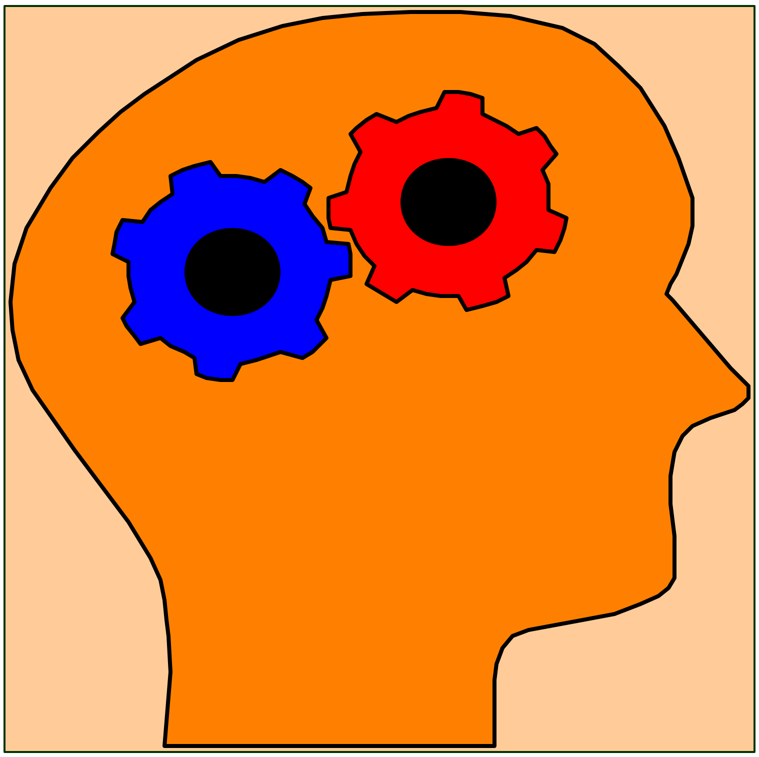
COMPLEXITY:



A COGNITIVE BARRIER TO

DEFENSE SYSTEMS ACQUISITION MANAGEMENT

Complexity:
A Cognitive Barrier to
Defense Systems Acquisition Management

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

By

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Dedication

In Memoriam

Margaret S. Perino

January 23, 1909 – April 19, 1999

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ABSTRACT

COMPLEXITY: A COGNITIVE BARRIER TO DEFENSE SYSTEMS ACQUISITION MANAGEMENT

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George Mason University, 1999

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This research effort proceeded from the presumption that complexity is a matter of perspective; it resides within the observer, not the issue under investigation. It is the observer's inability to grasp the interplay of multiple factors and events that lead to the perception that problems, issues or systems are "complex." The researcher sought to find answers to the following question: Are members of the defense systems acquisition workforce prepared to meet the demands of complexity? Study participants included highly schooled engineering- and management-oriented government employees responsible for the acquisition and life-cycle support of large-scale socio-technical defense systems costing billions of taxpayer dollars. These individuals were attending an intensive 14-week course in systems acquisition management at the Defense Systems Management College (DSMC). The college is considered to be the premier center for learning about management principles and the Department of Defense systems acquisition process.

Major findings from the research were as follows:

- There was a predisposition for reductive reasoning and a reliance on a simplistic linear approach as a principal mode for managerial action.
- There was a widespread difference of opinion concerning the capacity of human learning powers relative to the scale of what is to be learned.
- There was a widespread difference of opinion concerning whether the site of complexity is intrinsic to a system under observation or resident in the mind of the observer.

The major conclusion drawn from the research is that the prevailing strategy for systems acquisition is Newtonian in its origin and linear in its essential characteristics. It embodies analysis and control of observable outcomes and drives managerial attention toward near-term time horizons. Such an approach may be appropriate for well-defined mechanistic systems, but is inappropriate when attempting to manage acquisition programs characterized by non-deterministic behavior. Successful management of the defense systems acquisition process and its products requires a paradigm shift of major proportion. Bringing about the transformation can be accomplished through organizational change and curriculum redesign. The transformation will be difficult so long as systems acquisition management personnel fail to recognize that complexity is endemic to the observer rather than an intrinsic system characteristic.

Key Words: complexity, cognitive barriers, cognitive blind-spots, cognitive overload, demands of complexity, emergent systems, killer assumptions, linear thinking, management, observer theory, problematic situations, problematique, public policy, socio-technical systems, systems acquisition, systems science, systems theory, systems thinking, technology.

Dissertation

Statement of the Problem

The nature of defense systems acquisition has undergone radical change during the 1990s. The end of the cold war has led to extreme reductions in defense spending in the United States and around the world. Downsizing of military forces and consolidation of the defense industry here and abroad have significantly altered the structure of the public and private sectors. These changes have been regularly reported on radio, on television, and in print. Yet, some things remain unchanged and, to a large extent, unrecognized. *Real-world defense systems acquisition problems are non-deterministic in their behavior*.[1] Decisions concerning the acquisition process and its products can and do result in unanticipated outcomes. This is true regarding problematic situations encountered in implementing systems acquisition reform as well as in efforts to match defense system capabilities with operational and support requirements. Defense systems cost American taxpayers billions of dollars. These programs periodically undergo intense media scrutiny and political debate. The resulting impact on individual acquisition programs can be chaotic. Effective management of defense system acquisition under

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[1] A growing body of literature provides ample support for such a premise. See, for example: Cambel (1993), De Greene (1993), Kiel (1994), and Waldrop (1992) for contemporary thoughts by systems thinkers. See also Fenster (1999) for a telling example of an acquisition management disaster within the Department of Defense.

these conditions clearly requires a high degree of technical, business, and political acumen. But, it also requires an understanding of the demands that such complicating factors place on managerial activities. The research reported herein was aimed at investigating the extent to which individuals undergoing systems acquisition management training within the Department of Defense are prepared to meet those demands[2].

Relevance to Public Policy

The challenge facing acquisition managers in the Department of Defense is not unique. It is reflective of the impact that technology has had on society at large. In modern times, technology has been the catalyst for unprecedented speed and magnitude of changes that quickly outstrip society's ability to keep pace. Humanity's inability to effectively manage socio-technical systems gone awry is readily apparent. The confluence of technical, organizational, and personal perspectives when faced with design and management of large-scale systems results in solutions marked by:

- Overconfidence in current technical knowledge.
- Failure to recognize interactions among system components that have been designed relatively independently.
- Failure to anticipate people problems and human responses in crises. (Mitroff & Linstone, 1993.)

[2] The Defense Acquisition Workforce Improvement Act (DAWAIA), Public Law 101-510, Title 10 U.S.C., was enacted to improve the effectiveness of the personnel who manage and implement defense acquisition programs. As part of the fiscal year 1991 Defense Authorization Act, it called for establishing an Acquisition Corps and professionalizing the acquisition workforce through education, training, and work experience.

There is good reason for the apparent inability to manage our large-scale systems, and that reason can ultimately be traced to the information processing limitations of the human cognitive apparatus (Waller, 1982). The inability of the human mind to process more than a few bits of information simultaneously is well known. The concept of a basic human memory unit or "chunk" was introduced by George A. Miller in his 1956 article on the magical number seven. Herbert A. Simon, in his 1974 article in Science, suggested that the number of chunks that could be held in the mind might be closer to five. John N. Warfield wrote in 1988 that, when attempting to grasp interrelationships, the magical number was more like three, plus or minus zero. It should come as no great surprise, then, that modern man is mentally ill equipped to cope, unaided, with the challenges inherent in large-scale socio-technical systems. The tendency is to under-conceptualize interrelationships, thereby avoiding cognitive overload. Under-conceptualization results in the insufficient understanding of problematic issues by any single individual or group of individuals with all the unfortunate outcomes that result (Warfield, 1991.)

Research Context

Problematic Situations: A Matter of Scale

We are not concerned here with resolution of problems that can be categorized as routine, those that require limited mental processing and whose outcome is readily observable. Rather, we are interested in problems characterized by effects that are distant from causes in time as well as in space—problems with few, if any, obvious trigger points that can be used to produce significant and lasting change. Milan Zeleny (1977) recognized the role of scale in what we will refer to herein as "problematic situations" when he wrote that human systems management is not interdisciplinary or multidisciplinary, it does not attempt to unify scientific disciplines, it transcends them. Such is our view of complexity and the cognitive challenges it presents in all forms of human endeavor. Those challenges are of such scale that a trans-disciplinary paradigm is required for effective problem resolution.

Complexity: A Matter of Perspective

As yet, there is no agreed-upon explicit definition of complexity, although there are various operational descriptions (Cambel, 1993). This research effort proceeded from the presumption that complexity in the defense systems acquisition process is a matter of perspective; *it resides within the observer, not the system under investigation*. It is the observer's inability to grasp the interplay of multiple factors and events that lead to "complex" problems, issues or systems. We believe there is strong support in the literature for such a position and the need to make a clear distinction between use of the word "complex" as an adjective and our focus on the word "complexity" as a noun. In our view, complexity is a result, not a cause of confusion regarding the system, situation or issue under consideration.

The Role of the Observer

According to Fisher (1991), the first to emphasize the peculiar situation of the observer was R. J. Boscovich in his "De Spatio et Tempore" written in 1758. In Fischer's words: "Boscovich claimed that the observer can never observe the world as it is—only the interface (or difference) between him and the world." This notion of the observer's role was central to America's pre-eminent 19th century philosopher, Charles Sanders Peirce who wrote about the triadic relationship between object and "interpretant" through sign or symbol (Paynter, 1968; Hoopes, 1991.) The basic triadic act is naming—creating a symbolic bridge between subject and object. It is the interpretant, the observer, who constructs the bridge. Without an observer, there is no observation. It follows that if the observer names the object, complexity is in the observer's mind, not in the object under investigation. Despite these early insights regarding the nature of complexity, the philosophical bent growing out of the machine age resulted in an overshadowing emphasis on objectivity and the deterministic, mechanistic, and reductionist perspective of late 19^{th} and early 20^{th} century science.

The ideas of Boscovich and Peirce regarding the role of the observer resurfaced with the emergence of systems science following World War II. Herbert A. Simon (1962) may have planted seeds of semantic confusion when he wrote his now classic article on the architecture of complexity. The central thrust of the article makes the point that systems are hierarchical, but the reader is left with the impression that such systems are intrinsically complex. The thought that complexity is an intrinsic system characteristic is reinforced by Simon's often retold parable of the watchmakers Hora and Tempus.[3] Mitroff and Linstone (1993) maintain that separation of subject and object is a paradigm

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[3] According to the parable, Hora and Tempus both made very fine watches. Both were highly regarded and the phones in their workshops rang frequently as new customers were constantly calling them. Hora prospered, but Tempus went bankrupt. Why? Both watches consisted of about 1,000 parts each, but Tempus so constructed his watches that he had to restart construction from scratch whenever a customer interrupted his work. Hora's watches were no less complex, but he had designed them so that he could put together subassemblies of about ten elements each. Hence, when Hora had to put down a partly assembled watch in order to answer the phone, he lost only a small part of his work, and he assembled his watches in only a fraction of the man-hours it took Tempus. Simon had used this parable to make his point that the evolution of complex systems is dependent on a buildup of stable subsystems.

that underlies much of the approach to physical, social and management science education even today.

Several proponents of systems science did take specific note of the observer's role in characterizing the nature of systems. C. West Churchman (1968) wrote that it is a silly and empty claim that an observation is objective if it resides in the brain of an unbiased observer. W. Ross Ashby (1956) defined a system as any set of variables that the observer or experimenter selects from those available on the "real machine." Accordingly, any system definition is only a model of reality constructed subject to the observer's limitations of purpose and thought. Charles Francois (1997) refers to Heinz von Foerster as originator of the statement that objectivity is the cognitive version of the physiological blindspot. Robert Rosen (1977) specifically states that complexity is in the eye of the observer. George Klir (1991) reinforces the idea that complexity pertains to the observer when he writes: "Since we deal with systems distinguished on objects and not with the objects themselves, it is not operationally meaningful to view complexity as an intrinsic property of objects."

The Demands of Complexity

The aim of classical 19th century science was to discover in all systems, some underlying simple level of operation where deterministic and time-reversible laws of nature applied. In the classical perspective, there was a clear-cut distinction between what was considered to be simple and what had to be considered as complex. The concept of complexity within systems thinking has evolved considerably since that time (Cambel 1993, De Greene 1993, Klir 1991.) Several schools of thought have arisen during the latter half of the 20th century to address the management of complexity (Warfield, 1996a.) The research results reported herein build on the science-based approach to the management of complexity initiated by John N. Warfield over 25 years ago.

We find the following words penned by Warfield (1995) to be the most powerful reason for the thrust of our research effort. They clearly identify where complexity resides and underscore the need for a paradigm shift in the managerial approach to problematic situations. “To misplace the origin of complexity in the object of inquiry, instead of in the mind of the observer, is to commit an error that is unlikely to be undone…. If, however, it is correctly realized that complexity is in the mind of the beholder, the possibility of reducing complexity through learning processes comes to the fore.” Thus, we embarked upon a line of research aimed at identifying cognitive barriers to be overcome if we are to be successful in understanding the nature of complexity. And, we chose to pursue that research in an educational institution dedicated to improving the systems acquisition management process.

The Research Question

We sought to find an answer to the following question: Are members of the defense acquisition workforce prepared to meet the demands of complexity?

Methodology

Input for analysis was gathered through questionnaires administered to highly schooled engineering- and management-oriented government employees responsible for the acquisition and life-cycle support of defense systems. Virtually all participants were college graduates with ten or more years of on-the-job experience. Most held bachelor degrees in an engineering or business discipline and many held masters degrees as well. Study participants included acquisition professionals attending the 14-week Advanced

Program Managers Course (APMC) and members of the faculty at the Defense Systems Management College (DSMC) located at Fort Belvoir, Virginia. The college is considered to be the premier center for learning about the Department of Defense (DoD) systems acquisition process. Successful completion of APMC is considered essential for selection as a program manager of a major defense systems acquisition program. The research effort comprised three separate studies conducted between January, 1996 and February 1999. Over 875 individuals from seven acquisition management courses participated in the research project. A combination of content analysis as described by Weber (1990) and non-parametric statistical analysis as described by Siegel & Castellan (1988) was selected as an appropriate set of procedures for analyzing most participant responses to self-administered survey instruments. Random sampling and inferential statistical analytical techniques were applied to the extent practical. Significant reliance on non-random purposive sampling permit us to describe what was discovered, but not to state generalizable conclusions concerning the associations or patterns uncovered. This restriction was deemed acceptable since participant demographics generally reflect the composition of the Department of Defense acquisition workforce.

Findings

Barriers to the Interpretation of Structural Graphics

The first study focused on interpretation of graphical displays designed to aid in the management of complexity. To enhance the practical benefits of this research effort, we chose to use graphical displays noted for their track record as viable management tools. A set of graphical displays, known as Interpretive Structural Models, met this requirement. They are the product of a process called Interactive Management (IM) developed by Dr. John N. Warfield, a pioneer in the management of complexity through systems design. The IM process, products, and scientific foundations are described in the many publications of Dr. Warfield and his colleagues (Warfield, August 1990, 1996b). Graphical displays can be an extremely efficient means of communication *if the viewer understands the rules of construction*. However, rules for proper construction of interpretive structural graphics are not easy to articulate. Furthermore, visual skills, unlike talking, reading, and writing skills have been left dangling by our Western educational system (Eisner, Winter 1993). *To presume intuitive understanding of graphical displays is erroneous. Research in the field of visual literacy points out that while looking may be a given, seeing is an achievement* (Feinstein & Hagerty, 1994). We limited our investigation to an interpretive structural model designed to facilitate problem definition and resolution. It is the model most often developed first in the IM process and the one most often subject to misinterpretation by first-time viewers. The graphical display of this model is called the *problematique* (Warfield and Perino, 1999). The purpose of this study was twofold:

- To identify common misperceptions of the problematique among first-time viewers.
- To identify likely causes for their misinterpretation of graphical syntax.

It was anticipated that such information would facilitate development of educational material aimed at increasing viewer comprehension[4]. Over 475 acquisition professionals

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[4] A clear understanding of the problematique's syntax is key to the success of Warfield's "observatorium" whose purpose is to communicate information through large-scale displays (1996c). The observatorium is a building designed to enable someone to transition from overview to detailed knowledge by physically moving through a series of rooms containing structural graphic displays. Design of the structure provides the visual linkage necessary to reduce cognitive overload.

participated in this research. Results showed significant misinterpretation of the problematique. Although participants had little or no prior training in the use of this display, we were surprised by the significant misinterpretation of the display's format and underlying logic even when written instructional material was provided. The percentage of correct answers was frequently less than expected even if responses had been chosen at random. The average score among the 170 respondents asked to interpret a problematique without benefit of instruction was 22%. The average score among 314 respondents with access to written instruction was only 45%. *Analysis of narrative responses to questions about the meaning of the display led us to conclude that participants were predisposed to reductive reasoning and emphasis on cause and effect as a principal mode of thought*. To the extent that this conclusion is valid, it provides cause for concern regarding effective management of the DoD systems acquisition process. That process is lengthy and complicated. It is subject to technical as well as political perturbations. Both the process and its products are socio-technical in nature. As such, they are emergent, not mechanistic in behavior. Taking management action based on a paradigm of determinism invites repeated failures in program execution and a terrible waste of national resources. Details regarding this phase of the research can be found in appendix A.

Managerial Assumptions about the Nature of Complexity

The second study focused on participant opinions regarding the nature of complexity. John N. Warfield (1998) has identified a series of assumptions he believes people make about the nature of complexity. He feels these assumptions interfere with the effective management of large-scale problematic situations to such a degree that he has labeled them as "killer assumptions." Warfield has also identified a series of demands that complexity places on management. The demands of complexity are the antithesis of the killer assumptions. The purpose of this second study effort was to assess how widely each, if any, of the killer assumptions might be held among individuals responsible for managing the acquisition and life-cycle support of national defense systems. This study included 85 APMC attendees and 28 faculty at DSMC and was completed in December 1998.

The results of this study indicate that acquisition professionals do lack an appreciation for the demands of complexity, thus lending support for Warfield's hypothesis concerning the extent to which the killer assumptions underlie the mismanagement of problematic situations. Forty percent or more of the respondents chose the same four killer assumption statements--the essence of which suggest that resolution of large-scale problems presents no unique challenge. *The two most frequently combined killer assumptions were that human learning powers are independent of what is to be learned and that complexity is in the system being observed.* This is worrisome as it indicates that overcoming cognitive barriers to the management of problematic situations will be a daunting task. Conversely, strength of opinions held about the other 13 killer assumptions was not very high. Perhaps, there will be less resistance to changing opinions regarding the demands of complexity in those areas.

It was also encouraging to find that faculty were not as likely to choose killer assumption statements as were the course attendees. However, it would be unwise to discount the importance of Warfield's hypothesis that educational institutions fail to prepare students to deal adequately with the demands of complexity (Warfield, 1997.) This is particularly so given the apparent level of faculty confidence in human cognitive abilities. Over 60% of the faculty participants in this study agreed with the statement that human learning powers are independent of the scale of what is to be learned.

The overall results of this study indicate a pressing need to train acquisition professionals to respect the demands of complexity, yet fulfilling this need will be difficult so long as academicians and practitioners alike continue to overestimate human cognitive ability to contend with large-scale problematic situations. Details regarding this phase of the research can be found in appendix B.

The Nature of Systems and Problem Solving

The third study involved over 300 acquisition professionals and focused on obtaining their opinions regarding the nature of systems and problem solving. Results of the first two studies had led us to wonder about participants' perspective regarding systems theory. As previously stated, most survey participants held undergraduate and graduate degrees in engineering or business management subjects. The curriculum of the systems acquisition management course they were attending addressed both theory and practice in systems management tools and techniques, yet survey responses had often reflected a simplistic approach to problem solving. We therefore determined that important insights about this phenomenon could be gained by obtaining APMC attendee responses to the following three open-ended questions:

- What definition of "system" do you think is most useful?
- What does "problem solving" involve?
- How might "system behavior" be best understood?

Input was obtained by administering a one-page questionnaire and applying content analysis procedures to the responses. *Analysis disclosed a predominantly Newtonian* *perspective among the participants*[5]. *Well over half the respondents felt that system behavior could be best understood through observation and analysis. Almost the same proportion described a problem solving process that did not include getting feedback to determine if the chosen solution was working*. These results gave weight to suspicions raised during our earlier studies that acquisition professionals were overly focused on near term observable outcomes. Details regarding this phase of the research can be found in appendix C.

Aggregate Findings

This research effort sought to answer the following questions: are members of the defense acquisition workforce prepared to meet the demands of complexity. Three studies were conducted. The purpose of the first was to determine if first-time viewer comprehension of a problematique can be improved by providing written instruction. The purpose of the second was to determine which if any of Warfield's killer assumptions are widely held among defense systems acquisition professionals. The purpose of the final study was to gain insight to acquisition professionals' view of systems management. Combining the results of those three studies led us with the following aggregate findings:

- Acquisition professionals share a predisposition for reductive reasoning and a reliance on a simplistic linear approach as a principal mode for managerial actions (study #1 and #3).

[5] By Newtonian, we mean an investigative approach, born in the 17th century, that proved successful working with systems characterized by a very small number of variables, a high degree of determinism, and suitable for analytical treatment. Problems with such characteristics have been referred to as problems of organized simplicity (Klir, 1985).

- There is a widespread difference of opinion among acquisition professionals concerning the capacity of human learning powers relative to the scale of what is to be learned (study #2).
- There is a widespread difference of opinion among acquisition professionals concerning whether the site of complexity is intrinsic to a system under observation or resident in the mind of the observer (study #2).

Conclusions

Results of the research support a contention that defense systems acquisition professionals are not adequately prepared to deal with complexity when attempting to manage the non-deterministic aspects of large-scale systems acquisition programs. The prevailing strategy for systems acquisition is Newtonian in its origin and linear in its essential characteristics. It embodies analysis and control of observable outcomes and drives managerial attention toward near-term time horizons. Such a strategy may be appropriate for well-defined mechanistic systems, but is inappropriate when attempting to manage problematic situations encountered during the defense systems acquisition process.

Recommendations

The curriculum of the Advanced Program Management Course at DSMC emphasizes a linear flow from the establishment of war fighter requirements, through systems development, production, life cycle support, and disposal. Relatively little attention is paid to challenges faced when existing socio-technical systems must be modified to meet new or changing requirements. *Iterative processes such as pre-planned product improvement (P^3I), spiral development, or evolutionary acquisition are treated* *as aberrations rather than the norm. Such an educational approach flies in the face of reality given current emphasis on extending the life of existing systems.* There is a pressing need for a paradigm shift regarding management of defense systems acquisition programs. The following actions are recommended for DSMC management to help bring about the transformation:

- Make provisions for educating faculty, staff and acquisition professionals regarding the demands of complexity
- Increase emphasis within the curriculum on the use of science-based methods for resolving complexity such as Interactive Management.
- Augment the functional faculty organization to facilitate a trans-disciplinary approach to the application of management principles.

Bringing about the educational transformation can be accomplished through the recommended actions. The transformation will be difficult so long as acquisition professionals fail to recognize that complexity is endemic to the observer rather than an intrinsic system characteristic.

The findings, conclusions, and recommendations presented herein pertain specifically to members of the defense systems acquisition workforce attending the 14-week Advanced Program Management Course at DSMC. Those individuals may be unique in the level of education and experience they bring to the academic environment, but they are the products of America's educational institutions. There is abundant evidence from this study to suggest the need for research regarding the educational paradigm underlying engineering and business management education in the United States. Results of such research may identify a need for organizational change and curriculum reform within our colleges and universities to produce graduates able to meet the demands of complexity as they attempt to resolve the large-scale socio-technical problems facing our nation.

Postscript

Correspondence between Dr. George Friedman, retired chief technical officer for Northrop Corporation, and Dr. John Warfield was made available to this author as the preparation of this dissertation was nearing completion (see appendix D.) Dr. Friedman stated that one of the most demanding tasks he had at Northrop was to review the failures of new systems and technologies as they were going through their final test phases. He noted that test failures were due to two fundamental causes:

- The construction and assembly of the components did not follow the engineers' specifications.
- The models the engineers used to predict performance were incomplete; many of the interactions were omitted, despite the presence of massive computer resources.

Dr. Friedman indicated that the second cause was more prevalent than the first and stated, "This, in my mind, is yet another example of the dimensional limitations of our cognitive equipment." The point of his correspondence was to underscore his belief that quantitative modeling of the scientific and engineering worlds is inherently flawed by the fact that the humans who develop the equations controlled their experiments in accordance with their own cognitive limitations. I include reference to the correspondence here for two important reasons:

- It provides contemporary empirical evidence about human cognitive limitations and the role of the observer in describing system characteristics.
- It supports our recommendation for research regarding the paradigm underlying engineering and management education at colleges and universities in the United States.

Appendix A

Barriers to the Interpretation of Structural Graphics

Overview

The first of our three study efforts focused on interpretation of graphical displays designed to aid in the management of complexity. To enhance the practical benefits of this research effort, we chose to use graphical displays noted for their track record as viable management tools. A set of graphical displays, known as Interpretive Structural Models, met this requirement. They are the product of a process called Interactive Management (IM) developed by Dr. John N. Warfield, a pioneer in the management of complexity through systems design. The IM process, products, and scientific foundations are described in the many publications of Dr. Warfield and his colleagues (Warfield, August 1990, 1996b). Graphical displays can be an extremely efficient means of communication *if the viewer understands the rules of construction*. However, rules for proper construction of interpretive structural graphics are not easy to articulate. Furthermore, visual skills, unlike talking, reading, and writing skills have been left dangling by our Western educational system (Eisner, Winter 1993). To presume intuitive understanding of graphical displays is erroneous. Research in the field of visual literacy points out that while looking may be a given, seeing is an achievement (Feinstein & Hagerty, 1994). We limited our investigation to an Interpretive Structural Model designed to facilitate problem definition and resolution. It is the model most often developed first in the IM process and the one most often subject to misinterpretation by novice viewers. The graphical display of this model is called the *problematique* (Warfield & Perino, 1999). The purpose of this study was aimed at finding ways to increase viewer comprehension of the problematique by:

- Identifying common misperceptions of the problematique among "novice" viewers.
- Identifying likely causes for their misinterpretation of the graphical syntax.

It was anticipated that such information would facilitate development of educational material aimed at increasing viewer comprehension. Over 475 survey respondents participated in this research. We were surprised by the significant misinterpretation of the display's format and underlying logic even when written instructional material was provided. Analysis of responses to questions about the meaning of the display led us to conclude that participants were predisposed to reductive reasoning and emphasis on cause and effect as a principal mode of thought.

Statement of the Problem

Defense systems acquisition involves the interaction of multiple organizations, both public and private, as well as multiple functions within those organizations. Failure to recognize the interactive and emergent nature of the socio-technical activities and events involved often leads to unanticipated outcomes, which further complicate matters for acquisition managers within both the public and private sectors. Access to ever-increasing amounts of data tends to result in information overload rather than wiser decision-making.

Graphical Displays as a Potential Solution

All manner of potential solutions to this problem have been suggested, tested, and adopted; some resulting in greater benefit than others. One technique that appears to have a good deal of merit is the use of graphical displays to make visible the structural nature of problematic situations. Verbal and written descriptions suffer from the inherent linearity of prose. Attempts to process multiple thoughts simultaneously often lead to cognitive overload. Seeing the interplay of individual elements significantly reduces the mental activity needed to grasp the essence of the problem. Visual representation makes explicit what can only be implicit in a prose description (Sims-Knight, 1992).

Interpretive Structural Models

One set of graphical displays that have emerged as viable management tools is known as Interpretive Structural Models. These models depict transitive relationships[1]. They are products of a group process called Interactive Management (IM). Composed of simple graphics symbols and short prose statements, these models can take a number of forms depending upon the purpose of the IM session. An initial session might focus on problem definition, whereas follow-on sessions typically shift to the identification of alternative solutions, selection of the preferred alternative, and development of an implementation plan. The names

[1] The concept of transitivity is often illustrated as follows: If A impacts B and, if B impacts C, then A also impacts C. Failure to recognize such propagating relationships can result in unexpected and frequently embarrassing reactions to well-intended managerial initiatives.

given to models tend to reflect their purpose. For example, the model developed during the problem definition phase is called a *problematique*. Other models are given such names as *option field*, *priority structure*, and r*esolution structure*. Each is a two-dimensional graphical representation of relationships among sets of elements. Elements typically include such things as problems, options, activities, events, or decisions whereas relationships are frequently stated in terms of influence, affinity, priority or time precedence.

The Interactive Management Process

The IM process and its products are an outgrowth of the work of Dr. John N. Warfield, a pioneer in the field of managing complexity through systems design. In essence, the process systematizes human and computer interaction in ways that free individuals to think creatively and intuitively during group problem-solving sessions by relieving them of process management and documentation requirements. The Interactive Management process has proven to be a superior management support system for dealing with complexity. The process has been used in a very large number and variety of real-world applications. The results achieved during IM sessions demonstrate that participants can come away with a much clearer grasp of actions required to resolve problems than has been previously possible. However, experience also demonstrates that some IM products can be subject to misinterpretation when seen for the first time. This study effort investigated the use of written instructions as means for increasing viewer comprehension of the Interpretive Structural Model known as the problematique.

The Problematique

An Interactive Management session aimed at developing a problematique typically begins with a form of idea writing in response to a *trigger* question in a format similar to the following: “What are the critical factors which inhibit your ability to meet cost and schedule objectives?” The purpose of the trigger question in this type of IM session is to identify barriers to success. Each participant is given an opportunity to respond with as many ideas as possible. Each idea, stated in the form of a short sentence, is then posted for all to see and discuss. New ideas occurring during the discussions are also added to the list of elements to be considered. The discussion and idea generation process continue until participants feel they have identified and understand all inhibitors that come to mind. Participants are then asked to select those elements that they feel are the most critical for management action. These statements subsequently undergo an IM structuring process. The participants engage in a computer-assisted pair-wise comparison of critical elements in response to a *generic* question. A companion generic question to the foregoing trigger question might take the following form: “In the context of improving your ability to meet cost and schedule objectives, does factor “A” significantly increase the severity of factor “B”? Factor “A” would be one of the selected statements. Factor “B” would be another. The result of this process is the Interpretive Structural Model known as the problematique. An example of a problematique that resulted from the foregoing process is shown below. It portrays the negative influences among selected defense system acquisition process problem categories (Alberts, 1995)

Figure A1. An Example of a Problematique

The Research Question

Experience gained during many Interactive Management sessions suggests that each viewer needs some degree of initial assistance in the interpretation of a problematique. Prose has been the historical medium in education. Years of practice at reading, writing and thinking in the linearity of prose can lead to misinterpretation of Interpretive Structural Models (Warfield, December 1990). However, this problem is not limited to IM products alone. Levie and Lentz (1982) also found that a major problem with other graphical displays is that learners are not practiced in making effective use of them. Thus, we proceeded from a perspective that IM products, as currently portrayed and described in publications authored by Dr. Warfield, are fundamentally appropriate for the information to be conveyed and that ability to accurately perceive meaning can be improved by educating the viewer. Our research hypothesis was that providing written instructions on the format and logic of a problematique would result in significantly greater viewer comprehension.

Research Participants

Input for analysis was gathered through questionnaires administered to highly schooled engineering- and management-oriented government employees responsible for the acquisition and life-cycle support of defense systems. Virtually all participants were college graduates with ten or more years of on-the-job experience. Most held bachelor degrees in an engineering or business discipline and many held masters degrees as well. Study participants were attending the Advanced Program Management Course (APMC), an intensive 14 week course in systems acquisition management at the Defense Systems Management College (DSMC) located at Fort Belvoir, Virginia. The college is considered to be the premier center for learning about the Department of Defense systems acquisition process. Successful completion of the course is considered essential for selection as a program manager of a major defense systems acquisition program. These individuals represent a group of public and private sector decision-makers faced with managing the acquisition and life cycle support of U.S. Department of Defense (DoD) systems costing American taxpayers billions of dollars. These individuals and the society they serve would benefit greatly from effective use of structural graphics in managing the systems acquisition process.

Research Design

Our research was aimed at finding ways to increase viewer comprehension of the interpretive structural model known as the problematique. Our focus was not on the use of graphics as aids to understanding prose, but as a self-contained means of communication. Real-world management time is limited and subject to many distractions. Busy people try to make intelligent decisions in a “sound-bite” environment. Our research was aimed at increasing the problematique’s contribution to the wisdom of those decisions.

Our research effort entailed a two-phase approach to data collection and analysis. Phase one built upon the anecdotal evidence gathered by Warfield and Cardenas (1992). Emphasis was placed on identifying common causes for misinterpreting a problematique. A second goal was to test for the impact of written instruction on viewer comprehension. Phase two tested for increased viewer comprehension as a result of improvements in educational material suggested by the outcome of phase one. Both phases called for gathering data from viewers with little or no prior training or experience with the Interactive Management process or Interpretive Structural Models. [2]

Phase One Results

Phase one was conducted during the late summer and early fall of 1996. A research design based on non-random purposive sampling techniques was adopted in an effort to obtain a sufficient number of survey responses from which to draw useful information. Self-administered survey instruments were used to gather objective and subjective responses to questions concerning viewer interpretation of a problematique. A combination of nonparametric statistical analysis as suggested by Siegel & Castellan (1988) and content analysis as described by Weber (1990) was selected as the most appropriate set of procedures for analyzing this data. Use of non-random purposive sampling techniques permit us to describe what was discovered, but not to state generalizable conclusions concerning the associations or patterns uncovered. This restriction was deemed acceptable since participant demographics generally reflect the composition of the Defense acquisition workforce.

[2] We subsequently found only a handful of individuals claiming they knew anything about the IM process or its products among respondents to all our surveys. We could discern little if any beneficial impact on their answers. As a result, all respondents were included in our analysis as representative of first time viewers of a problematique.

APMC 96-2 Survey

The Defense Systems Management College conducts multiple offerings of the Advanced Program Managers Course (APMC) during each federal government fiscal year and numbers these offerings consecutively. We conducted phase one of our research effort during APMC 96-2, the second offering in fiscal year 1996. Four versions of a survey instrument were used. All contained questions pertaining to respondent's prior training or experience with the Interactive Management process and its products. The surveys involved respondent interpretation of a problematique displaying selected elements of a manufacturing quality control problem experienced by the producer of an expensive hydraulic pump. The problematique from which the elements were drawn had been developed during an actual series of IM sessions that ultimately led to resolution of the quality control problem (Landenberger 1984.) The pump problem was chosen because it represented the type of management challenge that might be encountered during implementation of a system acquisition program. Each questionnaire contained an identical problematique to facilitate comparison of responses. Two of the four versions used forced-choice questions to test viewer comprehension of the relationships displayed. The other two versions used an open-ended answer format. All four versions provided participants with space to explain the rationale for their answers. Two versions contained a list of ten points to keep in mind when interpreting a problematique.[3] The other two did not. The essential characteristics of each version are shown in table A1.

Table A1. Essential Characteristics of Phase One Survey Instruments.

Version 1	Version 2
• Forced-choice questions. • Rationale requested. • No "reading" instructions provided	• Forced-choice questions. • Rationale requested. • "reading" instructions provided
Version 3 • Open-ended questions. • Rationale requested. • No "reading" instructions provided	Version 4 • Open-ended questions. • Rationale requested. • "reading" instructions provided

This survey instrument design permitted comparison of responses from viewers who received specific hints on how to read a problematique versus those who did not. It also permitted comparison of responses to forced-choice questions versus responses reflecting free-form perceptions of the problematique's format and logic. Finally, it provided a means for identifying patterns of rationale underlying participant responses.

We distributed a total of 420 surveys during phase one and collected 283 for a 67% response rate. The 283 responses were distributed among the four questionnaires as follows: 80 responses to version one, 60 to version two, 69 to version three, and 74 to version four.

[3] Copies of these surveys are included at Appendix A-1 and A-2. Copies of the other surveys

Analysis of the data collected during phase one of the research effort was undertaken in several steps.

The Impact of Instructions on Viewer Comprehension

Step one involved testing for the impact of instruction on viewer comprehension. This involved a comparison of test scores achieved on survey versions one and three against those on survey versions two and four. Versions two and four contained the instructions on reading a problematique; version one and three did not. The analysis focused on assessing whether written instructions resulted in significantly higher test scores, thereby suggesting a higher level of comprehension.

The number of correct responses to survey versions one and three were compared against those to survey versions two and four. Only 48% of the 149 respondents to survey versions one and three answered one or more questions correctly as compared to 60% of 134 respondents to survey versions two and four. Conversely, 52% of the respondents without instructions got a zero as opposed to 40% of the respondents with instructions. The percentage of respondents and the number of correct answers they achieved on the APMC 96-2 survey are shown in Figure A2.

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can be obtained from the author.

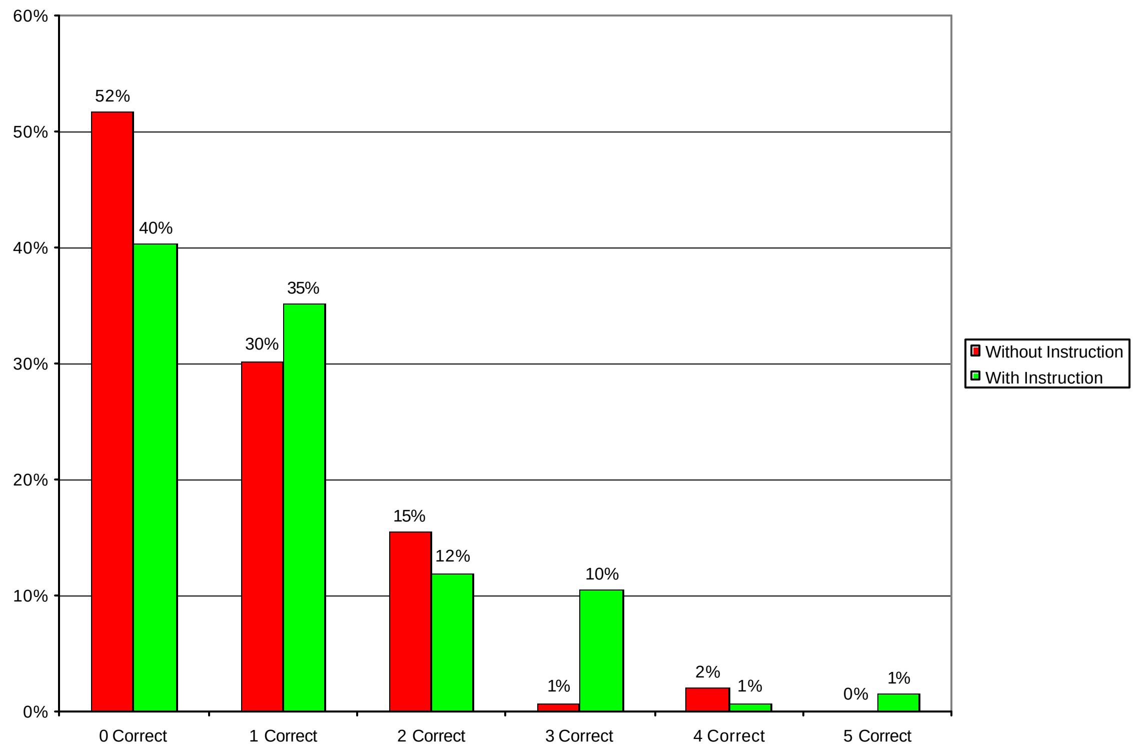

Figure A2. The Impact of Instruction on APMC 96-2 Results

The median number of correct answers achieved by all 283 respondents was one out of five possible. We collapsed the data into a 2 X 2 table in order to perform the Median Test using the Pearson chi-square statistic as described by Siegel and Castellan (1988). Table A2 shows the proportion of respondents scoring above the median and those that scored at or below it.

Table A 2. Impact of Instruction on APMC 96-2 Results

Respondents Scoring	Above the Median	At or Below the Median
With Instruction	25%	75%
Without Instruction	18%	82%
Totals	100%	100%

Although a comparison of the percentages seemed to indicate somewhat greater success when written instructions were provided, the null hypothesis that both groups came from the same population could not be rejected (X^2 (1, *N* = 283) = 0.18). Thus, we could not hold that providing written instruction made a significant difference in test scores between these two groups.

Content Analysis

Step two involved the use of content analysis procedures described by Weber (1990) to analyze the narrative statements provided by respondents to all four versions of the APMC 96-2 survey. The purpose of this analysis was to develop a sense of the common misconceptions held by individuals viewing a problematique for the first time. Content analysis procedures require the investigator to develop an intimate relationship with the narratives being analyzed in order to gain a sense of intended meaning from what is stated and the context in which it is stated. The process requires the investigator to select a word or phrase to accurately capture the central thought in each response. A count of these words and phrases then provides input for a quantitative assessment of common ideas among all respondents.

Content analysis is an inductive process. It is highly subjective, time consuming, and laborious. As a result, its reputation suffers or benefits from the features of qualitative research, depending on one's viewpoint. We believed it to be an appropriate and valid process for identifying similarities in the way viewers interpreted the meaning of a problematique. We recognized that the results of our analysis would be highly exploratory and subject to investigator bias. We therefore attempted to avoid premature closure on the selection of code words and phrases to the maximum extent possible. After coding all responses to all questions in each version of the survey instrument, we systematically reviewed the results of our analysis and made changes in code words or phrases where consistency and comparability would benefit. For example, we had initially coded a series of responses to question three of the forced-choice version of the survey as “number of arrows” to reflect respondents’ references to the impact which the elements in one box would have on succeeding boxes. We then found we had coded somewhat similar responses to question four in the open-ended version of the survey with the code word “influence.” We adopted “influence” as a better descriptor of meaning since both questions involved similar intent. Such changes were limited as we attempted to minimize second-guessing our initial impression of a respondent’s intended meaning.

Although computer-aided content analysis software is becoming increasingly available, we felt that a manual process was more appropriate for this phase of our research as investigator selection of appropriate code words and phrases comprises the major portion of the effort. Our subsequent experiences during the coding of narrative responses confirmed what we had anticipated. Choosing the words and phrases for coding purposes was a true challenge intellectually and physically. Over 1,300 statements were coded during a period of several weeks. The length of time it took to complete this effort was as much a function of our ability to stick to the task as it was the time chunks available to do so.

When we had completed our initial coding effort, we found we had dozens of cases where a code word or phrase had been assigned only once. We tried collapsing these into broader categories, but found the effort of little benefit. Our initial coding efforts seemed to effectively highlight the major tendencies in viewer interpretation of the problematique. Our analysis identified only a few words or phrases that had been assigned with any consistency. The two most frequent were causality and fault isolation. These two words were assigned to 20% of the narrative responses to versions one and three (without instructions) and 15% of the narrative responses to versions two and four (with instructions.) [4]

Reasons Underlying Incorrect Responses

Step three involved a search for reasons underlying incorrect responses to the five forced-choice questions in survey versions one and two. The statements provided by respondents in support of answers were analyzed to gain a sense of the common misconceptions held by individuals viewing a problematique for the first time. Open-ended questions in survey versions three and four were also analyzed to gain a better perspective on reasons underlying incorrect responses. We shall describe the intent of each question, the choices respondents made, and the nature of the narrative comments as we interpreted them. A

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[4] Narrative statements provided by respondents for all questions together with the tag word or phrase assigned are available from the author.

copy of the problematique used in the phase one survey is provided in Figure A 3. The ten hints for "reading" a problematique included in versions two and four are listed below:

- A problematique depicts elements of a situation and propagating relationships among them.
- The concept of propagation is often described as follows. If A impacts B, and if B impacts C, then A also impacts C.
- Elements are contained within boxes.
- The arrow indicates the relationship.
- Bulletized elements within the same box are interrelated.
- The numbers in parentheses indicate the sequence in which elements were presented by the workshop participants. They are retained for tracking purposes and have no other connotation.
- Elements on the left are not necessarily the cause of elements to the right.
- The left-most elements are not necessarily root causes of the situation.
- The layout of a problematique results from efforts to minimize line-crossings. There is no intended suggestion regarding priority or duration of effort to resolve the situation portrayed.
- The thickness of lines and the size of boxes are not intended to suggest relative importance among the elements shown.

This problematique depicts some of the elements identified during a series of IM workshop sessions aimed at reducing hydraulic pump rejection rates. The elements shown below were among those considered most critical by the participants in response to the trigger question and were structured in response to the generic question.

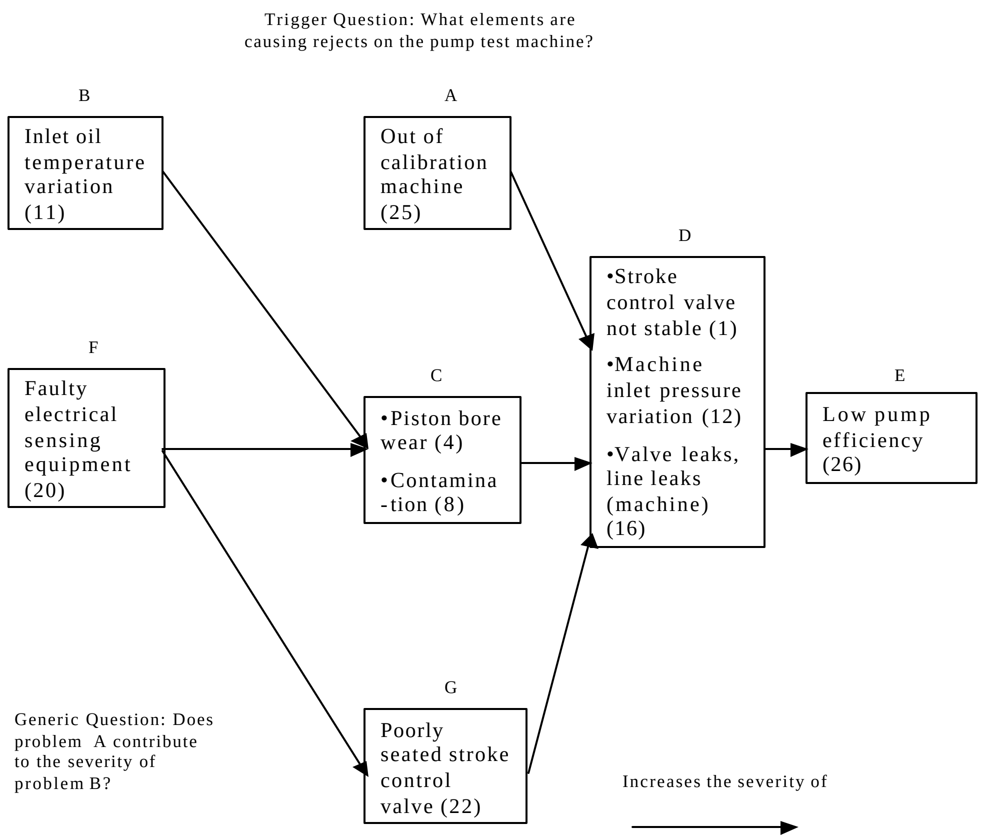

Figure A3. The Problematique Used in the APMC 96-2 Survey

Interpretation of cycles.

The first question addressed the nature of cycles. Cycles are common in problematiques. They are comprised of elements that interact with each other. Cycles require holistic attention; elements within them cannot be treated as isolated problems. The question posed and the percentage of respondents choosing each answer are shown in Table A3.

Table A3. The Interpretation of Cycles

The elements in Box C are best attacked:	Without Instructions	With Instructions	Totals
a. Sequentially	36%	20%	29%
b. In Parallel	34%	43%	38%
c. Makes No Difference	16%	18%	24%
d. None of the above[5]	10%	15%	17%
No Response	4%	3%	4%
Totals	100%	100%	100%

The correct answer to this question was "None of the above". Survey version one had no instructions concerning the meaning of cycles and there was no scientific rationale available to the viewer to support any of the other answers. The written instructions in version two, if considered by a careful reader, should have increased the probability of selecting the correct

[5] One might argue that answer d. should be "Unknown" rather than "None of the above." In fact, we used "Unknown" in two pilot surveys and found that most respondents choosing that answer tended not to provide any rationale thereby frustrating our efforts to gain insight to the thinking behind that selection. We therefore decided to use the less logical response, but one we felt would encourage inclusion of a rationale statement.

answer. Sixty-seven percent of the respondents chose to take either a sequential or parallel approach. Twenty-four percent felt it made no difference which approach was used, while only 17% chose the correct answer. It was our overall impression from analysis of narrative statements that the rationale most frequently provided by all respondents, whatever their choice of answers to this question, seemed to rest on the concept of cause and effect and a step-by-step approach to problem resolution based solely on the information placed before them.

A question focusing on the interpretation of cycles was also included in survey versions three and four. It asked what the respondent thought the managerial implications were when multiple elements were contained in the same box. This was an open-ended question. In our analysis of 134 responses, we tagged 21 with the phrase “interrelated elements.” We tagged 19 others as “related elements” and 33 as “share the same trait” or “share similar trait.” Only the first phrase was assigned to statements that seemed to capture the true meaning of cycles.

Interpretation of spatial relationships.

The results of prior research by Winn (1981, 1982) suggest that English speakers will tend to read a graphical display from left to right and from top to bottom. Winn and Solomon (1993) have conducted controlled experiments which demonstrate that items shown to the left of or above other items are assumed to be superior or inclusive of the items to the right or below. That which is shown to the left is thought by the viewer to be a cause, not a result. Those experiments did not include the use of arrows to show the direction of the relationship, as is the case with construction of a problematique. Question two in our survey instrument was designed to test for viewer comprehension of spatial relationships within a problematique. The question focused viewer attention on one box in a series. The box in question (Box G) was located at the bottom of the problematique. The box contained only one element. The question and answers chosen are shown in Table A4.

Table A4. The Interpretation of Spatial Relationships

The elements in Box G appears to be:	Without Instruction	With Instruction	Totals
a. A Fundamental Problem	36%	28%	33%
b. An Intermediate Problem	43%	30%	37%
c. A symptom, Not a Cause	8%	20%	13%
d. None of the above	10%	17%	13%
No Response	4%	5%	4%
Totals	100%	100%	100%

The correct answer was “None of the above”. There was no scientific rationale available to the viewer to support any of the other answers. Instructions in survey version two warned against the assumption of cause and effect. The instructions also indicated that the purpose of problematique layout is merely to minimize line crossings.

Fifty-two of 140 respondents (37%) felt that the element in box G was an intermediate problem. Most of their narrative statements suggested that an intermediate problem falls between other elements. Although that answer was chosen more often than any of the others, it was only marginally more popular the first answer. The respondents who chose that answer seemed to equate the term “fundamental” with the idea of cause and effect.

It was also of extreme interest to note that not one of the 140 respondents referred to the labeled arrow included in the display. That arrow was labeled, “increases the severity of.” That arrow was immediately to the right of the box in question, yet it was apparently ignored or misinterpreted to infer a causal relationship.

Prioritization of effort.

The third question attempted to uncover reasons why a viewer would choose to work on one element over another when there was no scientific basis for a choice. Viewers were asked to choose among three elements that were displayed at the top or leftmost position in the problematique. The boxes containing these elements had one or more arrows leading away from them and none leading to them. The intent was to invite a choice among elements that were visually endowed with relative equality. A fourth choice permitted the viewer to ignore the three elements in favor of some other element the viewer might consider more important. The question posed and the answers chosen are displayed in Table A5.

Table A5. Prioritization of Effort

Which element should be addressed first? The one(s) in (choose one):	Without Instruction	With Instruction	Totals
a. Box A	40%	32%	36%
b. Box B	3%	7%	4%
c. Box F	28%	20%	24%
d. None of the above[6]	21%	30%	25%
No Response	9%	12%	10%
Totals	100%	100%	100%

Once again, the correct answer was "None of the above" since there was no scientific rationale provided to support any other selection. Reading "hints" included in version two specifically stated that the format of the problematique does not mandate priority of effort to resolve the situation portrayed.

When all responses to this question in versions one and two were totaled, it appeared that two trains of thought were predominant in support of the choices made. Thirty six percent of the respondents chose box A and 24% chose box F. Each of those two boxes contained an element dealing with operating parameters or test equipment. The respondent's knowledge or experience with hydraulic pump systems presumably drove the choice between them. The second most common trend seemed to be that the more arrows leading away from a box, the greater the assumed impact or influence, and thus, the greater payoff for starting with that element.

Analysis of responses to the question in survey versions three and four that addressed prioritization of effort found quite similar results. That question asked respondents which element or elements they felt should be addressed first and why? Sixty five percent of those respondents chose box A, B, or F. This unconstrained choice pattern was virtually identical to the 64% of version one and two respondents forced to select from among box A, B, or F. Analysis of narrative statements provided by the two sets of respondents also showed similarities. Forty eight percent of the respondents to the forced choice version and 44% of the respondents to the open-ended version provided responses suggesting a mechanistic approach to problem solving.

Duration of effort.

The intent of question four in versions one and two was to test for viewer assumptions concerning duration of effort required to resolve multiple elements. We asked viewers to compare two cycles, one containing two elements and one containing three. The 3-element cycle (Box D) was to the right of the 2-element cycle (Box C). The 2-element cycle and two other separate elements led directly to the 3-element cycle. The question posed and the answers chosen are shown in Table A6.

[6] The results of our content analysis suggested that first-time viewers seem to assume that everything they need to know was being displayed before them. Only six respondents choosing "None of the above" cited lack of data as the reason.

Table A6. Duration of Effort.

Which group of elements will take longer to resolve? Those in (choose one):	Without Instruction	With Instruction	Totals
a. Box C	18%	15%	16%
b. Box D	64%	47%	56%
c. Neither	1%	3%	2%
d. None of the above	14%	22%	17%
No Response	4%	13%	8%
Totals	100%	100%	100%

The correct answer to this question was “None of the above” since there was no scientific rationale for any other choice. Reading hints provided in version two stated that a problematique layout was aimed at reducing line crossings and not to suggest anything regarding duration of effort required to resolve the situation portrayed. Over half the respondents felt that the elements in box D would take longer to resolve. Our analysis of narrative statements indicated that the number of inputs to Box D rather than the number of elements within it was the key factor leading to respondent decisions concerning duration of effort. This same logic was also reflected in responses to the question regarding duration of effort in survey versions three and four.

The Logic of Transitivity.

The purpose of question five was to test viewer comprehension of transitivity. Viewers were asked about the impact of resolving all elements in one of the boxes (Box C). That box had two boxes preceding it. One of those two boxes (Box B) led only to the box in question. The other box (Box F) also led to another element. The question posed and the answers chosen are shown in Table A7.

Table A7. The Logic of Transitivity

Resolving all the elements in box C will completely eliminate the impact of the element in (choose one):	Without Instructions	With Instructions	Totals
a. Box B	48%	30%	40%
b. Box F	4%	7%	5%
c. Neither	24%	25%	24%
d. None of the above	21%	28%	24%
No Response	4%	12%	7%
Totals	100%	100%	100%

In this instance the correct answer was "Neither" since eliminating an element in a string of transitive relationships does not break the predecessor's link to elements succeeding the one eliminated. Our evaluation of the statements made by all the respondents left little doubt that the concept of transitivity was not well understood, even among those respondents who had the benefit of the instructions. We interpreted 72 out of 130 narrative statements as indicating a chain-like linkage among elements in the minds of respondents. In other words, resolving an element along a pathway of arrows severed a connection between the elements that remained.

There were two open-ended questions and one forced-choice question concerning the concept of transitivity and its propagational characteristics in our phase one survey instruments. One of the open-ended questions asked respondents about the meaning of the relationship portrayed by the arrow. The arrow was labeled “Increases the severity of.” The arrows connecting elements that comprise a problematique indicate the direction and extent of the propagating relationship. A correct interpretation would have indicated that any element along a path of arrows increases the severity of all subsequent elements on that same pathway. Only 28 of 138 participants mentioned increased severity in their response and it was not clear if they truly understood the impact of propagation. Sixty nine other respondents expressed their understanding in a manner that seemed to reflect a paradigm of causality rather than influence. Their statements tended to infer that an antecedent element was necessary before a succeeding element could occur. Twelve respondents saw linkage, but did not specify what kind. These three categories accounted for 76% of the responses to that question.

The other open-ended question asked how resolution of elements on the left would impact those to their right. Half the respondents believed that some form of positive change would occur. Individual responses referred to the outcome as enhanced performance, reduced occurrence, and reduction or elimination of succeeding elements, in addition to the anticipated response of reduced severity. Another 13% were not sure what the outcome would be.

Discussion of Phase One Results

Phase one focused on analysis of data gathered from 283 respondents. The purpose of that data collection effort was twofold. First, to gain a better understanding of causes for misinterpretations of problematique format and content. Second, to test for the impact of instruction on viewer comprehension. Non-random purposive sampling techniques were used.

As a result, our findings are descriptive in nature and establish a baseline for follow-on inferential research efforts. As stated earlier, we performed the Pearson Chi-Square test to determine if there was a statistically significant difference in the responses provided by participants who had the benefit of instruction on “reading” a problematique. Surprisingly, our analysis indicated that providing written instruction made no significant difference in success rates. Narrative responses to the phase one surveys were analyzed for common threads. Although not statistically significant, several recurring themes enabled us to hypothesize three potential reasons why first-time viewers tended to misinterpret the problematique. They were:

- Misinterpretation of the meaning and significance of cycles.
- Lack of understanding of the concept of transitive propagation.
- Preconceived notions concerning spatial relationships among problem elements.

We will first discuss our findings and conclusions regarding viewer interpretation of cycles, a phenomenon common to problematiques of any consequence. Second, we discuss survey results concerning the concept of transitive propagation and the challenge it posed for respondents to our initial survey instrument. Lastly, we address the impact that spatial relationships in a problematique appear to have on viewer comprehension.

The Interpretation of Cycles

All elements forming a “cycle” influence each other in the same fashion. If the transitive relationship being portrayed is one of aggravation or increased severity, each element within the same cycle will aggravate or increase the severity of all other elements within that same cycle.

The essential characteristic of a cycle is one of interrelationship. Thus, the elements within the cycle must be treated collectively in the pursuit of effective problem resolution. Whether a collective treatment is best performed sequentially or in parallel requires additional data and analysis. Two questions attempted to discern viewer interpretation of cycles. No prior instruction concerning the meaning of cycles was provided in any survey instrument. Omission was intentional. It is well known that visual proximity connotes togetherness. Including interrelated elements within the same box and preceding each element with a dot portrays a cycle. By omitting any reference to the nature of cycles, we were able to elicit each participant's own interpretation concerning what the elements within the same box shared in common.

The problematique used in the survey addressed reducing hydraulic pump rejection rates. Many APMC attendees have engineering degrees or job experience and appeared to have some familiarity with the operation of pumps and techniques used in their repair. Upon reflection, this apparent familiarity with the subject matter may have given respondents confidence in their ability to determine the best approach without additional analysis. For example, 20 of the 41 individuals choosing to pursue a sequential approach referred to a cause and effect relationship among the elements that suggested what was, to them, an obvious first step. Eleven others wished to pursue a fault isolation approach to resolving the cycle. These two categories of rationale accounted for 76% of the reasons why respondents chose a sequential approach. A total of 53 out of 140 respondents chose to take a parallel approach. Although not the correct response, we had expected this choice to be popular among those who grasped the essence of a cycle. However only 11 of the 53 cited the interrelationship among the elements in their rationale. Somewhat surprisingly, 17 cited the impact of multiple elements external to the cycle as the reason for a parallel approach to the multiple elements within the cycle. Why these individuals chose to focus on antecedent elements remained unclear until we sensed that a cause and effect paradigm underlay their thinking.

Our overall impression of responses to the two questions concerning the nature of cycles was that participants had no difficulty with the idea of togetherness, but differed significantly concerning the course of action to be taken as a result of it. Relatively few seemed to truly understand the nature of the interrelationship portrayed. Almost all seemed willing to take a position based on the limited information provided. Only a handful felt that additional data was needed before initiating action to resolve the problem.

The Concept of Transitive Propagation

The concept of transitivity is often described as follows. If one item relates to a second, and the second to a third, then the first also relates to the third in the same manner. If for example, A equals B, and B equals C, then A also equals C. Conversely, if C is equal to B, and B is equal to A, then C is also equal to A. If B is eliminated, C is still equal to A. Similarly, if C is influenced by B, and B is influenced by A, then C is also influenced by A. If B is eliminated, C is still influenced by A. *It is this latter form of the transitive relationship that underlies the logic of the problematique*.

The transitive relationship portrayed in a problematique is normally one of aggravation. Predecessor elements make successor elements worse. The impact propagates. For example, if A aggravates B, and if B aggravates C, then A also aggravates C. In the logic of a problematique, the severity of C reflects the combined affect of B, as it is aggravated by A, as well as A, itself, as shown below in Figure A4. A problematique is constructed using the convention shown to the right of the equal sign so as to minimize line crossings and enhance perceptibility. Since the propagating relationship is one of influence, not causality, removal of B does not eliminate the adverse impact of A on C. Conversely, eliminating A does not prevent either B or C from occurring.

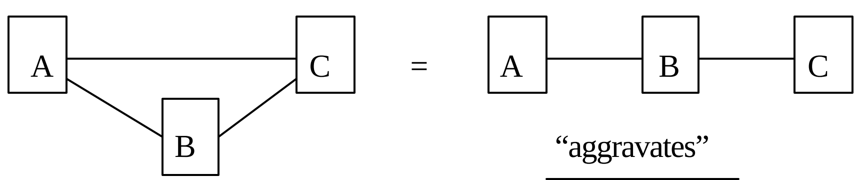

Figure A4. Transitive Propagation

The power of the problematique as a management tool lies in its potential for making the propagating linkage among the elements visible to those who must resolve them. Taking all responses to these three questions into account, we believe that one of the reasons why the instructions on how to “read” a problematique were not effective in improving viewer comprehension was that the essential difference between transitive propagation and causality was not adequately explained or understood. In addition, we suspected that the difficulty English readers have in understanding a problematique is due to left-to-right analysis of a display portraying a right-from-left logic. If the viewer understood that both A and B aggravated C, and that B was also aggravated by A, we suspect that the viewer would understand that removal of B does not eliminate the impact of A on C.

Spatial Relationships and Viewer Comprehension

English speakers have learned to read prose from left to right and from top to bottom. Research by Winn and Solomon (1993) demonstrated that English readers make certain assumptions regarding spatial relationships. We were concerned that such assumptions could lead to unwarranted conclusions regarding issues of precedence and duration regarding individual elements and the effort required resolving them. While there is some logic to attributing greater influence to elements on the left as opposed to those on their right, such an assumption must be treated as a hypothesis subject to verification. Likewise, while it may be logical to assume that elements to the right in a problematique may have more factors influencing them than elements to their left, there is no basis for any assumption concerning the length of time it will take to resolve them. In other words, based on the problematique alone, one might hypothesize, but cannot conclude that the leftmost elements deserve some higher priority of attention and that rightmost elements will take longer to resolve.

Both the forced-choice and open-ended versions of our survey contained questions intended to test for the impact of spatial relationships on viewer interpretation of problematique format. What we found was that spatial relationships seemed to have somewhat less of an impact among this entire group of survey participants than other, more content related, aspects. Only 42% of the respondents seemed to focus on the spatial relationship among elements as a basis for prioritization. Most of the other respondents cited reasons having to do with cause and effect, fault isolation, and expediency as a basis for their choice of elements to receive priority attention. When it came to duration of effort, only 46% of the respondents chose elements to the right over elements to their left. Those who felt that elements to the left would take longer to resolve also tended to cite content rather than format related aspects as a basis for their answer.

Based on our interpretation of the overall reaction to these and the other questions posed in our initial survey effort, we suspect that first time viewers who feel quite familiar with the content presented in a problematique may jump to conclusions as to its managerial implications. Conversely, we suspect that individuals who are not familiar with the subject matter may be more apt to focus on format when trying to interpret the resulting problematique. These suspicions find support in research by Winn (1988) regarding instructional diagrams and the amount of detail displayed therein. He found that the more explicit the details, the more likely viewers are to pay attention to them at the expense of looking at the whole diagram. This suggests to us that respondents who were more familiar with the operations of hydraulic pumps, or who had engineering backgrounds, tended to place less emphasis on the diagrammatic aspects of the display. In essence, we believe they saw more immediately comprehensible “detail” in the prose and focused on it at the expense of comprehension available through the format of the display. We also suspect that a paradigm of deconstructionism underlay the interpretation that survey participants gave to the problematique placed before them. The logic of cause and effect and the atomistic analytical techniques derived from it are a part of every day life for engineers and scientists. We believe the tendency to take apart and segment technological problems spills over into the scientific aspects of managerial research and education. To the extent these impressions are true, they pose significant implications for attempts to educate individuals who have not participated in an Interactive Management session, but are expected to understand and implement the recommendations that ensue from them.

Phase Two Results

Phase two built upon findings from phase one. It involved development, testing, and use of revised survey instruments during 1997 and 1998. Random sampling and inferential statistical analysis was used to the extent practicable. Revisions to the phase one survey instruments were threefold:

- First, a set of new written instructions expanded on the concept of transitive propagation, the interpretation of cycles, and the relevance of spatial relationships. Graphics were added to help readers visualize key concepts prior to seeing a problematique for the first time.
- Second, the multiple-choice and open-ended questions were combined in one survey instrument and several questions were added in an effort to verify an individual's understanding of key concepts.

- Third, we were concerned that the nature of the original problematique might have significantly biased responses from participants with education and experience in engineering disciplines. We decided to test a substitute problematique involving the issue of system acquisition reform—a subject studied by all APMC attendees as part of their curriculum at DSMC. This second problematique had been developed during a series of IM workshops aimed at improving the system acquisition process within the Department of Defense. As such it was highly relevant to changes in acquisition policy being driven by congressional mandate and implemented under the guidance of the Secretary of Defense.

The Defense Systems Management College conducted three of the 14-week acquisition management courses during 1997. When multiple survey versions were used, they were distributed randomly among attendees. They were asked to fill out the surveys on their own time as had been done during phase one. Response rates were significantly, and disappointingly, less than achieved during phase one. The relatively poor response rates were likely due to the heavy emphasis placed on the voluntary nature of attendee participation by the college administration at the time the surveys were distributed. In addition, two of the three survey efforts were conducted late in the 14-week course when attendees had little enthusiasm or patience for any activity not required for graduation. The research effort and results for each of these three classes are discussed below.

APMC 97-1 Survey

A total of 300 surveys were distributed during week nine of the first 14-week course conducted in 1997. The DSMC course number, which we shall use for convenience hereafter, was APMC 97-1. This survey effort focused on the interplay of instruction sets and problematique types. Four versions were randomly distributed among the attendees.[7] We paired the original set of instruction with the hydraulic pump problematique in one version and with the new acquisition reform problematique in another. We also paired each problematique with the new set of instructions. The essential characteristics of these four versions and the results achieved are shown Table A8.

Table A8. Essential characteristics of APMC 97-1 Survey Instrument

Version 1 Original instructions with hydraulic-pump problematique 7 responses received Average Score 35%	Version 2 Revised instructions with hydraulic-pump problematíque 8 responses received Average Score 48%
Version 3 Original instructions with acquisition-reform problematique 4 responses received Average Score 57%	Version 4 Revised instructions with acquisition-reform problematique 9 responses received Average Score 44%

Only 28 surveys were returned during week ten for a response rate slightly less than ten percent. A comparison of average scores indicated that the number of respondents answering questions correctly seemed to improve some over results achieved by phase-one participants.

However, when one-way analysis of variance (ANOVA) was applied to the data, the results did not show that overall scores achieved by any of the four groups responding to the survey were significantly different from each other ($F (3, 24) = 1.0012$). We did use the Student T-Test to check results regarding the concepts of transitive propagation, cycles, and spatial relationships and found significant differences in three instances. Respondents did better generally on questions pertaining to cycles ($t\ (54) = 3.98$, $p < .001$) and transitive propagation ($t\ (54) = 2.36$, $p < .05$) than they did regarding spatial relationships. Respondents with the new set of instructions did significantly better on questions concerning cycles than respondents with the old set ($t\ (26) = 3.77$, $p < .001$). There was no statistically significant difference in result regarding transitive propagation, cycles or spatial relationships when scores achieved on the acquisition reform problematique were compared against those achieved on the hydraulic pump problematique.

APMC 97-2 Survey

Due to the low response rate to the APMC 97-1 survey, we decided to abandon use of the hydraulic pump problematique and concentrate on acquisition reform in an effort to capture attendee interest. Three survey versions were randomly distributed to 240 attendees during week two of APMC 97-2.[8] Once again, attendees were allowed to complete the survey without supervision on their own time. Sixty-six surveys were returned the next week for a 27.5% response rate. All three versions asked identical questions about the acquisition reform

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[7] Copies of each version are available from the author.

problematique. One version contained no instructions. A second version contained the original list of ten "reading" hints. The third contained the set of expanded instructions expected to result in the best performance by first-time viewers. The essential characteristics of this survey are shown in Table A9.

Table A9. Essential characteristics of APMC 97-2 Survey Instruments

Version One	Version Two	Version Three
No instructions	Original "list" instructions	Revised instructions
21 responses received	22 responses received	23 responses received
Average score: 34%	Average score: 45%	Average score: 51%

The three group results were compared using one-way ANOVA. Results indicated a significant difference in the data (F (2, 63) = 7.25, $p < .01$). The Student T-test was used to compare versions two and three against version one and against each other. Respondents with the original set of instructions did statistically better overall than those without any instructions (t (41) = 2.39, $p < .05$) as did respondents with the new set of instructions (t (42) = 3.94, $p < .001$). However, the revised set of instructions did not prove to be significantly more beneficial than the original set (t (43) = 1.30).

We also analyzed results regarding the concepts of cycles and transitive propagation as well as the meaning given to spatial relationships. Questions concerning these three topics were grouped to determine the total number of correct answers given by the respondents relative to the total possible number of correct responses. Results are summarized in Table A10.

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[8] Copies of each version are available from the author.

Table A10. APMC 97-2: Results Regarding the Interpretation of Cycles, Transitive Propagation and Spatial Relationships

	Version 1: No Instructions 21 Respondents	Version 2: Original Instructions 22 Respondents	Version 3: Revised Instructions 23 Respondents
The meaning and significance of cycles	Number of - questions: 3x21=63 correct answers: 26 Percent correct: 41%	Number of - questions: 3x22=66 correct answers: 40 Percent correct: 61%	Number of - questions: 3x23=69 correct answers: 53 Percent correct: 77%
The concept of transitive propagation	Number of - questions: 5x21=105 correct answers: 28 Percent correct: 27%	Number of - questions: 5x22=110 correct answers: 47 Percent correct: 43%	Number of - questions: 5x23=115 correct answers: 53 Percent correct: 46%
The meaning given to spatial relationships	Number of - questions: 8x21=168 correct answers: 43 Percent correct: 26%	Number of - questions: 8x22=176 correct answers: 52 Percent correct: 30%	Number of - questions: 8x23=184 correct answers: 61 Percent correct: 33%

Differences in the percentage of correct answers showed that the meaning and significance of cycles, while not easy, was less difficult to understand than the concept of transitive propagation or the interpretation of spatial relationships for this group of participants. Even without instructions, this group scored higher, on average, in response to questions on the meaning and significance of cycles than they did regarding the meaning to be given to spatial relationships (t (40) = 2.84, $p < .001$).

Both sets of instructions were of significant help with regard to understanding cycles and the concept of transitive propagation, but seemed ineffective in overcoming confusion regarding the lack of meaning to be associated with spatial relationships. Scores achieved on the survey with the original instructions were statistically higher regarding cycles (t (41) = 1.69, $p < .05$)

and transitive propagation (t (41) = 2.04, $p < .05$) than scores achieved without instruction. Respondents getting the revised set of instructions also did better regarding cycles (t (42) = 3.19, $p < .001$) and transitive propagation (t (42) = 2.84, $p < .001$). However, the revised set of instructions was not significantly of greater help than the original list of reading hints.

APMC 97-3 Survey

A single version of the survey utilizing the revised instructions together with the acquisition reform problematique was distributed to 60 attendees during week 13 of APMC 97-3.[9] Only nine surveys were returned before the end of the course for a 15% response rate. This number was deemed insufficient for in-depth analysis; however, a cursory review of responses did suggest the need for minor changes in the instruction set to be used on further surveys.

Overall, the results of research conducted during 1997 were considered to be beneficial in that the format of the survey instrument was put through what could be considered as three separate pilot tests, thereby increasing our confidence in its usefulness to gather additional data. Thus, plans were made to survey the first acquisition management course in fiscal year 1998 and to do so early in the course.

APMC 98-1 Survey

Only one version of the survey was used to collect data from individuals attending APMC 98-1. The set of instructions that combined text with graphics was used together with

[9] A copy of the survey is available from the author.

the acquisition reform problematique[10]. The instruction set was modified slightly from that used in 1997 in an effort to expand the test for respondent understanding of transitive propagation. The survey form included a simple combination of problem elements, in problematique format, to interpret immediately following written explanation of the graphical syntax. This provided us with data about respondents' ability to intuitively "see" all the relationships being portrayed when viewing a problematique. It also provided us with an indication of the extent to which instructions were actually being read before answering questions about the acquisition reform problematique.

The survey was administered during a scheduled class period to 124 attendees in four sections of APMC 98-1[11]. A total of 98 surveys were completed for a response rate of 79%. The high rate of participation is attributed to conducting the survey during week two of APMC 98-1 and to the fact that it was on the official class schedule.

Since one of the sections surveyed was comprised of senior military and civilian personnel and another had an extremely low rate of participation, we tested the null hypothesis that there was no statistically significant difference in performance among the four sections using

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[10] A copy of the survey is located at Appendix A-3.

[11] APMC 98-1 was comprised of 370 attendees placed in 12 sections. The college administration normally assigns attendees to sections with a view toward balancing the mix of military service, gender, and military rank or civilian grade. This approach results in groupings that reflect a reasonable cross-section of the total population of each class and to a great extent, the mix of all APMC attendees. There is one exception to this procedure. When the number of senior grade attendees is large enough, the administration will place them in a separate section. This was the case with APMC 98-1. One of the four sections surveyed was comprised of

one-way ANOVA. The null hypothesis could not be rejected at the .05 level of significance (F (3, 94) = 0.92), therefore we combined all responses for further analysis.

Respondents to the APMC 98-1 survey repeated the relatively poor performance encountered in phase one. The average percentage of correct answers among respondents to the APMC 98-1 survey was 48%. Scores ranged from a high of 91% to a low of 0%. Sixty-nine percent of the 98 respondents scored 50% or less. Analysis of responses concerning the three concepts that seemed most troublesome to previous respondents was conducted for APMC 98-1. The relative difficulty in understanding problematique syntax previously encountered was also repeated. The meaning and significance of cycles seemed easiest to grasp followed by the concept of transitive propagation, and the meaning given to spatial relationships. The percentage of correct answers regarding cycles, transitive propagation, and spatial relationships is shown in Table A11.

Table A11. APMC 98-1: Percentage of Correct Answers

The meaning and significance of cycles	Number of questions:3x98=294 Correct answers: 195 Percent correct: 66%
The concept of transitive propagation	Number of questions:5x98=490 Correct answers: 214 Percent correct: 44%
The meaning given to spatial relationships	Number of questions:8x98=784 Correct answers: 200 Percent correct: 26%

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military rank 06 and civilian grades GS15 or higher. All other sections were comprised predominantly of military rank 05 and civilian grades GS 14 and lower.

There were three questions pertaining to the meaning and significance of cycles. These questions were answered correctly 66% of the time. Five questions focused on the concept of transitive propagation. Respondents answered these questions correctly 44% of the time. The eight questions pertaining to spatial relationships faired even worse. Respondents answered these questions correctly only 26% of the time. Once again, respondents did significantly better when answering questions about cycles than transitive propagation (t (194) = 5.31, $p < .001$) and the meaning given to spatial relationships (t (194) = 10.64, $p < .001$). Responses to questions about transitive propagation were also significantly better than responses to questions about spatial relationships (t (194) = 4.78, $p < .001$).

Discussion of Phase Two Results

Phase two built upon findings from phase one. It involved development, testing, and use of revised survey instruments during 1997 and 1998. Random sampling and inferential statistical analysis was used to the extent practicable. Phase one survey instruments were revised in several ways:

- First, a set of new written instructions expanded on the concepts we found most frequently misunderstood among phase one participants: transitive propagation, the interpretation of cycles, and the relevance of spatial relationships. Graphics were added to help readers visualize key concepts prior to seeing a problematique for the first time.

- Second, the multiple-choice and open-ended questions were combined in one survey instrument and several questions were added in an effort to verify an individual's understanding of key concepts.
- Third, we tested a new problematique involving problems characteristic of the systems acquisition process.

We surveyed attendees at four APMC classes during 1997 and 1998. Data was gathered from 201 individuals, 180 of whom had the benefit of written instructions to aid in understanding the problematique presented to them. The results were not encouraging. We have come to believe that misinterpretation of problematique format and logic by first-time viewers is a predictable phenomenon and we are not optimistic that written instructions alone can overcome the misinterpretations we have uncovered. Practitioners of the IM process may wish to make use of written instructions prior to displaying a problematique for the first time in an IM session. However, verbal emphasis on correct interpretation of display syntax should become part of standard IM session agendas. Writers of IM session after-action reports should also anticipate misinterpretation of a problematique by the majority of individuals that did not personally participate in the IM session. Great care will likely be needed in briefing IM session sponsors and other stakeholders expected to take action as a result of IM session recommendations.

Conclusions

This study began with a fairly simple goal—to discover barriers to the interpretation of structural graphics and to see if written instructions could overcome those barriers. We believe the results of this research effort provide substantial evidence that the conceptual underpinnings of the problematique are subject to predictable misinterpretation. Of greater import are the reasons for this phenomenon. As we reflected upon the pattern of responses and narrative comments made by survey respondents, we came to the following conclusions:

- The participants in this study had no prior experience with the Interactive Management process or its products, yet they took the information presented in the form of a problematique at face value as if it were complete and valid.
- The concepts of cycles and transitive propagation and the meaning to be given spatial relationships were counterintuitive to this group of participants.
- These participants were predisposed to reductive reasoning and emphasis on cause and effect as a principle mode of thought.

To the extent these conclusions are valid, they provide cause for concern regarding effective management of the DoD systems acquisition process. That process is lengthy and complicated. It is subject to technical as well as political perturbations. Both the process and its products are socio-technical in nature. As such, they are emergent, not mechanistic in behavior. Taking management action based on a paradigm of determinism invites repeated failures in program execution and a terrible waste of national resources.

Appendix A-1

APMC 96-2 Survey Version 2

Interpretive

Structural Models

APMC 96-2

Survey Version #2

The following questions are intended to help us determine how prior knowledge concerning interpretive structural models may impact your responses to survey questions. Please be sure to answer each question.

1. Process Knowledge: How familiar are you with the group deliberation process known as Interactive Management?

a. I know nothing about the process _____

b. I know something about the process, but would not feel comfortable trying to explain it to someone else _____

c. I think I could explain how the process works, after a brief refresher _____

d. I can explain how the process works right now _____

2. Product Knowledge: How familiar are you with the products produced through the group deliberative process known as Interactive Management?

a. I know nothing about the products _____

b. I know something about the products, but would not feel comfortable trying to explain them to someone else _____

c. I think I could explain what the products are, after a brief refresher _____

d. I can explain what the products are right now _____

3. Training: Briefly describe any training you may have had with the Interactive Management process and/or its products.

4. Experience: Briefly describe any experience you may have had with the Interactive Management process and/or its products.

Important!

Please do not discuss the following information with anyone else. We are distributing different forms of the survey instrument to different individuals. Helping someone else answer their set of questions will destroy the validity of the survey. Thank you for your cooperation.

Thank you for agreeing to help us in our efforts to increase the usefulness of the graphical display you are about to see. Your answers to the questions contained in this survey will aid us in identifying ways to make future displays easier to understand.

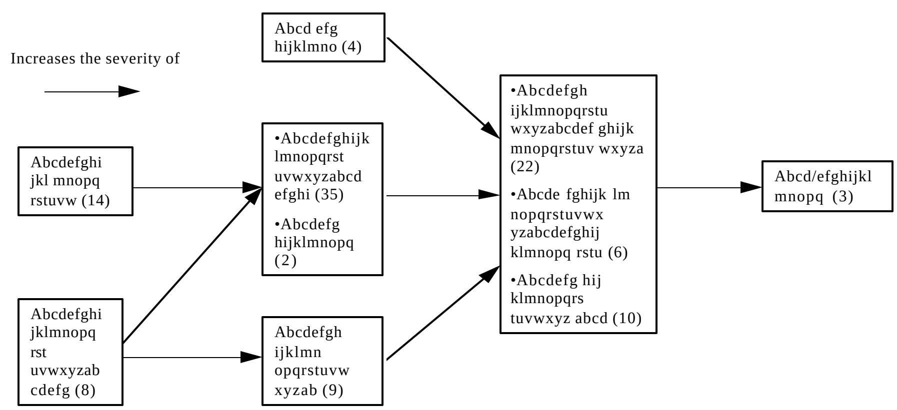
This survey is part of an ongoing effort to increase the usefulness of certain graphical displays intended to aid in the management of complex socio-technological situations. The general class of graphical display under study is the Interpretive Structural Model (ISM). This particular survey instrument focuses on an interpretive structural model known as the *problematique*. Before proceeding to the survey itself, we ask that you read the following material concerning the purpose of the problematique, the process by which it is developed, and some important clues to understanding what it means and does not mean.

Interpretive structural models are intended to aid in the understanding of complexity by presenting relationships in graphical form. The intent is to enable viewers to grasp the essence of the situation more quickly than would be possible if the relationships were to be described in one or more paragraphs of text. The problematique is one form of interpretive structural model. It is the result of a group deliberative process aimed at problem definition. Other interpretive structural models are developed during follow-on sessions aimed at identification of alternative solutions to the problem, selection of the preferred alternative, and development of an implementation plan. The ISM products developed during such sessions have been given the names *option field*, *priority structure*, and *resolution structure* to reflect their purpose.

The group deliberative process has been given the name Interactive Management (IM). The IM process and its products are an outgrowth of the work of Dr. John N. Warfield, a pioneer in the field of managing complexity through systems design. The process, products, and scientific foundations have been well documented in the many publications of Dr. Warfield and his colleagues. In essence, the IM process systematizes human and computer interaction in ways that free individuals to think creatively and intuitively by relieving them of process management and documentation requirements. These activities are performed by a trained facilitator and his or her support staff. Thus, the participants in an IM session can concentrate on content issues while avoiding the distraction of process management responsibility.

The problematique is developed during an IM session in a two-phase process. The first phase elicits participant ideas in response to a “trigger question” posed by the session’s sponsor. A typical trigger question takes the following form: “What are the critical factors which inhibit the ability to meet objective X?” Participants are not limited to the number of ideas they record. Each idea is recorded, numbered for tracking purposes, and discussed to insure understanding. The first phase concludes with each participant selecting ideas that merit immediate further processing. The second phase of problematique development involves a pair-wise comparison of this set of ideas to establish their relationships. The comparison is made in response to a "generic question" which might take the following form: " In the context of improving the ability to meet objective X, does element A significantly increase the severity of element B?" In this case, the elements being compared would be those ideas which the participants considered important enough to merit immediate follow-up. An example of a problematique is shown below. We have used nonsensical statements in this example to help you focus on format rather than content.

The Problematique



Prior research has shown that most English speaking readers will automatically begin "reading" visual material from left to right and from top to bottom. They may even experience noticeable mental discomfort when forced to follow a logic that unfolds in the opposite direction. This natural tendency can lead to erroneous presumptions about the meaning of information in a visual display. Please keep the following in mind when studying this problematique and the one you are about to be shown:

- A problematique depicts elements of a situation and propagating relationships among them.
- The concept of propagation is often described as follows. If A impacts B, and if B impacts C, then A also impacts C.
- Elements are contained within boxes.
- The arrow indicates the relationship.
- Bulletized elements within the same box are interrelated.
- The numbers in parentheses indicate the sequence in which elements were presented by the workshop participants. They are retained for tracking purposes and have no other connotation.
- Elements on the left are not necessarily the cause of elements to the right.
- The left-most elements are not necessarily root causes of the situation.

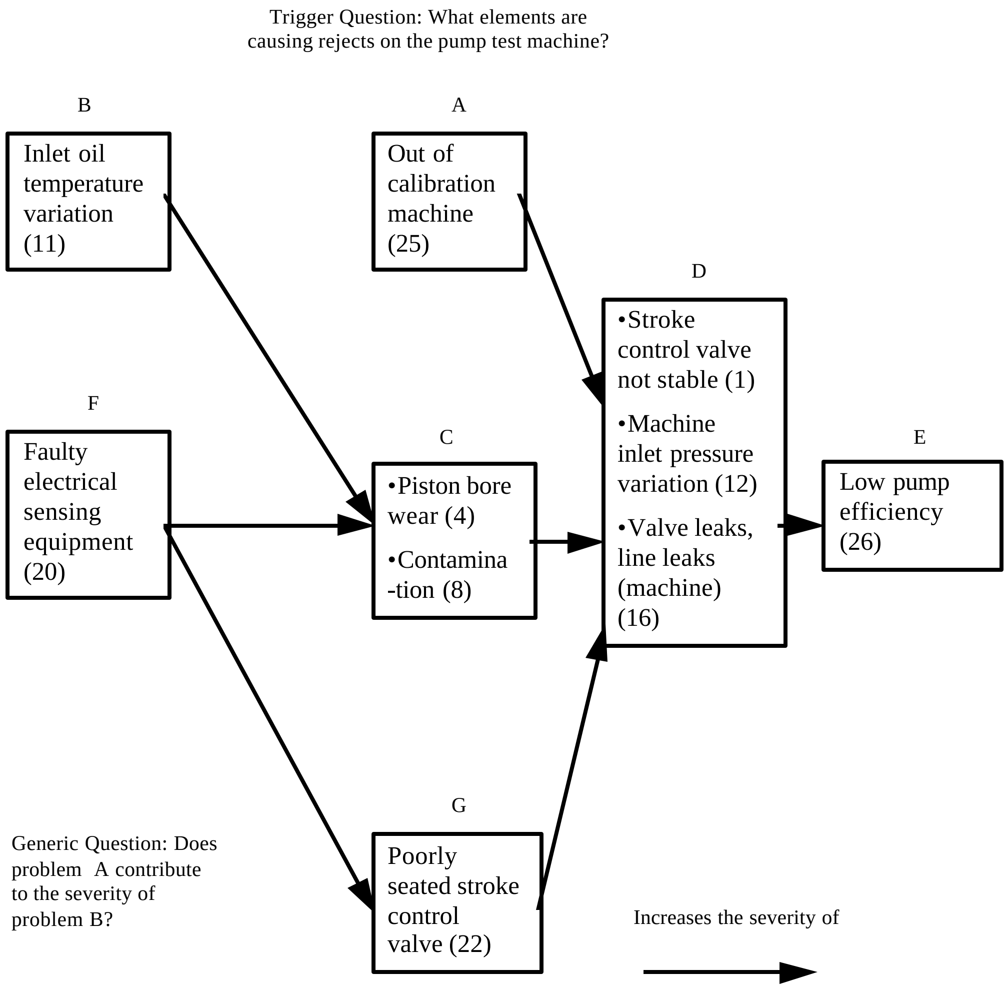
- The layout of a problematique results from efforts to minimize line-crossings. There is no intended suggestion regarding priority or duration of effort to resolve the situation portrayed.
- The thickness of lines and the size of boxes are not intended to suggest relative importance among the elements shown.

The following pages contain questions regarding the problematique you are about to see. Please answer the questions to the best of your ability. Providing an explanation of the reasoning behind your selection of an answer, when requested, will be most beneficial in our efforts to make Interactive Management products more user friendly. Thanks for your help.

Important!

Please do not discuss the forgoing information with anyone else. We are distributing different forms of the survey instrument to different individuals. Helping someone else answer their set of questions will destroy the validity of the survey. Thank you for your cooperation.

This problematique depicts some of the elements identified during a series of IM workshop sessions aimed at reducing hydraulic pump rejection rates. The elements shown below were among those considered most critical by the participants in response to the trigger question and were structured in response to the generic question.



Please answer the following questions based solely on you own interpretation of the information being displayed. *Explaining why you picked your answer is very important to our research.*

1. The elements in Box C are best attacked (choose one):

   a. Sequentially

   b. In Parallel

   c. Makes No Difference

   d. None of the above

Please explain the reason for your answer

2. The element in Box G appears to be (choose one):

   a. A Fundamental Problem

   b. An Intermediate Problem

   c. A Symptom, Not a Cause

   d. None of the above

Please explain the reason for your answer

3. Which elements should be addressed first? The one(s) in (choose one):

   a. Box A

   b. Box B

   c. Box F

   d. None of the above

Please explain the reason for your answer

4. Which group of elements will take longer to resolve? Those in (choose one):

a. Box C
b. Box D
c. Neither
d. None of the above

Please explain the reason for you answer

5. Resolving all the elements in box C will completely eliminate the impact of the element in (choose one):

a. Box B
b. Box F
c. Neither
d. None of the above

Please explain the reason for your answer

Appendix A-2

APMC 96-2 Survey Version 4

Interpretive Structural Models

APMC 96-2

Survey Version #4

The following questions are intended to help us determine how prior knowledge concerning interpretive structural models may impact your responses to survey questions. Please be sure to answer each question.

1. Process Knowledge: How familiar are you with the group deliberation process known as Interactive Management?

a. I know nothing about the process _____

b. I know something about the process, but would not feel comfortable trying to explain it to someone else _____

c. I think I could explain how the process works, after a brief refresher _____

d. I can explain how the process works right now _____

2. Product Knowledge: How familiar are you with the products produced through the group deliberative process known as Interactive Management?

a. I know nothing about the products _____

b. I know something about the products, but would not feel comfortable trying to explain them to someone else _____

c. I think I could explain what the products are, after a brief refresher _____

d. I can explain what the products are right now _____

3. Training: Briefly describe any training you may have had with the Interactive Management process and/or its products.

4. Experience: Briefly describe any experience you may have had with the Interactive Management process and/or its products.

Important!

Please do not discuss the following information with anyone else. We are distributing different forms of the survey instrument to different individuals. Helping someone else answer their set of questions will destroy the validity of the survey. Thank you for your cooperation.

Thank you for agreeing to help us in our efforts to increase the usefulness of the graphical display you are about to see. Your answers to the questions contained in this survey will aid us in identifying ways to make future displays easier to understand.

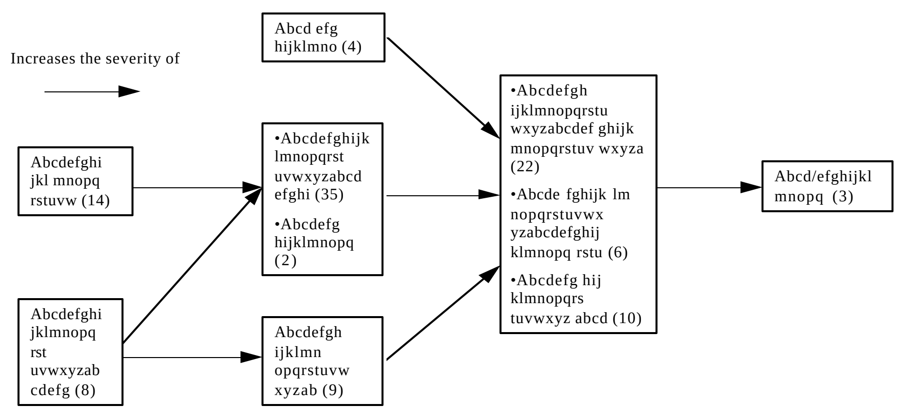
This survey is part of an ongoing effort to increase the usefulness of certain graphical displays intended to aid in the management of complex socio-technological situations. The general class of graphical display under study is the Interpretive Structural Model (ISM). This particular survey instrument focuses on an interpretive structural model known as the *problematique*. Before proceeding to the survey itself, we ask that you read the following material concerning the purpose of the problematique, the process by which it is developed, and some important clues to understanding what it means and does not mean.

Interpretive structural models are intended to aid in the understanding of complexity by presenting relationships in graphical form. The intent is to enable viewers to grasp the essence of the situation more quickly than would be possible if the relationships were to be described in one or more paragraphs of text. The problematique is one form of interpretive structural model. It is the result of a group deliberative process aimed at problem definition. Other interpretive structural models are developed during follow-on sessions aimed at identification of alternative solutions to the problem, selection of the preferred alternative, and development of an implementation plan. The ISM products developed during such sessions have been given the names *option field*, *priority structure*, and *resolution structure* to reflect their purpose.

The group deliberative process has been given the name Interactive Management (IM). The IM process and its products are an outgrowth of the work of Dr. John N. Warfield, a pioneer in the field of managing complexity through systems design. The process, products, and scientific foundations have been well documented in the many publications of Dr. Warfield and his colleagues. In essence, the IM process systematizes human and computer interaction in ways that free individuals to think creatively and intuitively by relieving them of process management and documentation requirements. These activities are performed by a trained facilitator and his or her support staff. Thus, the participants in an IM session can concentrate on content issues while avoiding the distraction of process management responsibility.

The problematique is developed during an IM session in a two-phase process. The first phase elicits participant ideas in response to a “trigger question” posed by the session’s sponsor. A typical trigger question takes the following form: “What are the critical factors which inhibit the ability to meet objective X?” Participants are not limited to the number of ideas they record. Each idea is recorded, numbered for tracking purposes, and discussed to insure understanding. The first phase concludes with each participant selecting ideas that merit immediate further processing. The second phase of problematique development involves a pair-wise comparison of this set of ideas to establish their relationships. The comparison is made in response to a "generic question" which might take the following form: " In the context of improving the ability to meet objective X, does element A significantly increase the severity of element B?" In this case, the elements being compared would be those ideas which the participants considered important enough to merit immediate follow-up. An example of a problematique is shown below. We have used nonsensical statements in this example to help you focus on format rather than content.

The Problematique



Prior research has shown that most English speaking readers will automatically begin "reading" visual material from left to right and from top to bottom. They may even experience noticeable mental discomfort when forced to follow a logic that unfolds in the opposite direction. This natural tendency can lead to erroneous presumptions about the meaning of information in a visual display. Please keep the following in mind when studying this problematique and the one you are about to be shown:

- A problematique depicts elements of a situation and propagating relationships among them.
- The concept of propagation is often described as follows. If A impacts B, and if B impacts C, then A also impacts C.
- Elements are contained within boxes.
- The arrow indicates the relationship.
- Bulletized elements within the same box are interrelated.
- The numbers in parentheses indicate the sequence in which elements were presented by the workshop participants. They are retained for tracking purposes and have no other connotation.
- Elements on the left are not necessarily the cause of elements to the right.
- The left-most elements are not necessarily root causes of the situation.

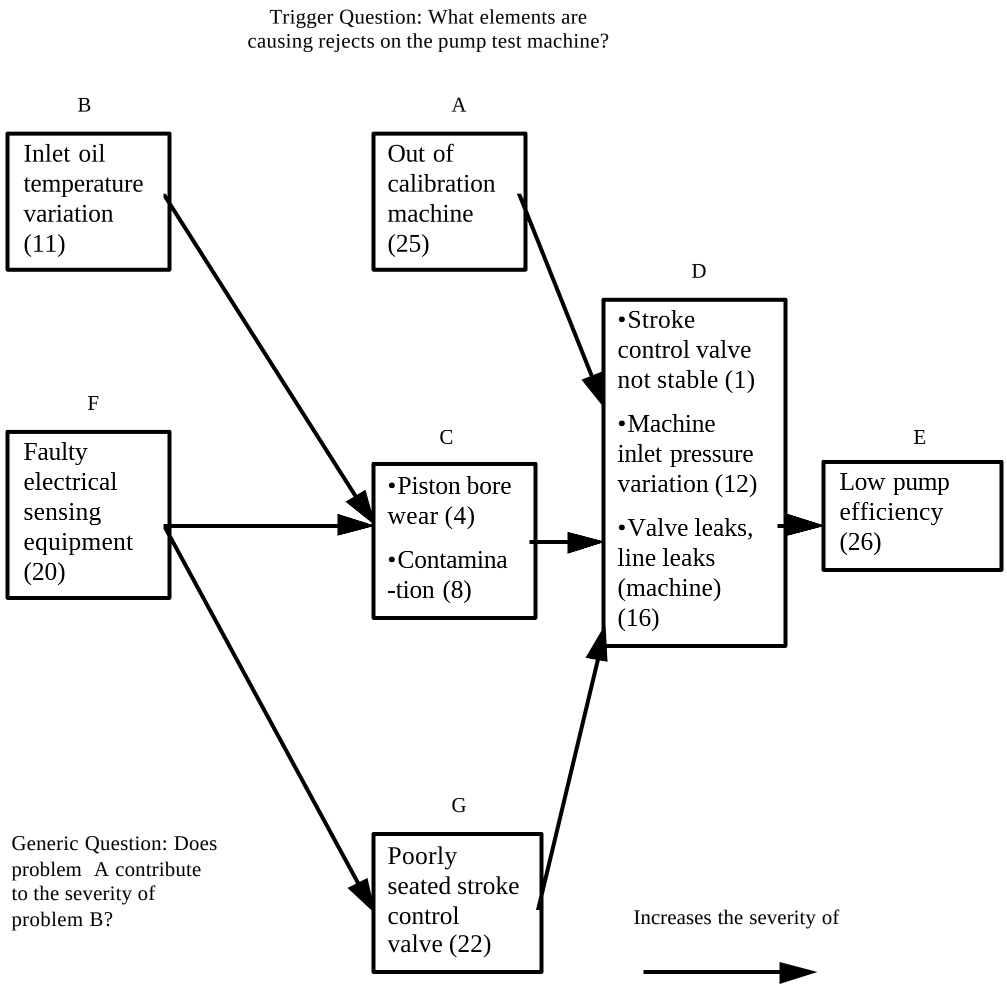
- The layout of a problematique results from efforts to minimize line-crossings. There is no intended suggestion regarding priority or duration of effort to resolve the situation portrayed.
- The thickness of lines and the size of boxes are not intended to suggest relative importance among the elements shown.

The following pages contain questions regarding the problematique you are about to see. Please answer the questions to the best of your ability. Providing an explanation of the reasoning behind your selection of an answer, when requested, will be most beneficial in our efforts to make Interactive Management products more user friendly. Thanks for your help.

Important!

Please do not discuss the forgoing information with anyone else. We are distributing different forms of the survey instrument to different individuals. Helping someone else answer their set of questions will destroy the validity of the survey. Thank you for your cooperation.

This problematique depicts some of the elements identified during a series of IM workshop sessions aimed at reducing hydraulic pump rejection rates. The elements shown below were among those considered most critical by the participants in response to the trigger question and were structured in response to the generic question.



Please provide brief answers to the following questions based solely on your own interpretation of the information being displayed.

1. What is the meaning of the relationships portrayed by the arrow?

2. What is the managerial implication, if any, when multiple elements occupy the same box? What is the basis for your conclusion?

3. How would resolution of elements on the left impact those to their right?

4. Which element(s) do you feel should be addressed first and why? (use the parenthetical numbers to indicate which element(s) you are choosing)

5. Which element(s) do you feel will require more effort to resolve and why? (use the parenthetical numbers to indicate which element(s) you are choosing)

6. Given what you see displayed before you, what do you feel is the next appropriate step or steps to take in resolving the situation portrayed?

Appendix A-3

APMC 98-1 Survey

Interpretive Structural Models

The Problematique

APMC 98-1

This survey is part of an ongoing effort to increase the usefulness of certain graphical displays intended to aid in the management of complexity.

It will take about 45 minutes of your time.

Participation is voluntary.

Thanks for your help.

SURVEY INTRODUCTION

This survey has been scheduled to collect research data on the interpretation of graphic aids used to display complex information. This effort is a DSMC faculty research project (CF-R-03: Enhancing Graphics as Aids to Education). Research results will benefit educational efforts at DSMC and program management activities in the field. Your participation is strongly encouraged, but completely voluntary.

Part of management training and education includes the use of tools and techniques designed to focus attention on the essentials. One set of tools that you may or may not know of are called *Interpretive Structural Models*. These models are designed to present the essential ingredients of a complex problem in a structured and visual way so that we can better see what faces us as we decide what action to take. Although these models have been used successfully here at DSMC and elsewhere in the federal government, experience indicates that one of the models may be subject to misinterpretation when seen for the first time. Our research is aimed at trying to understand how to minimize this misunderstanding.

The survey packet you will receive contains the following items:

- Questions concerning your prior knowledge of these models.
- Educational material concerning the process used to develop the Interpretive Structural Model called the *Problematique*.
- Instructions on how to interpret the problematique.
- An example of a problematique developed in support of acquisition reform.
- A set of 16 questions concerning your *independent* interpretation of that problematique.

Part of our research is concerned with the interplay of the Myers-Briggs Type Indicator *preference scores* and interpretation of the problematique. We will ask that you give us your permission to access the MBTI data that will be archived in the Managerial Development Department database.

Be assured that any personal data we collect will be grouped together so that nothing about you will ever be made public. The validity of our research findings will rest on the total number of responses we receive, not on individual entries.

PLEASE DO NOT TURN THE PAGE UNTIL INSTRUCTED TO DO SO.

The following questions are intended to help us determine how prior knowledge concerning interpretive structural models may impact your responses to this survey. *Please be sure to answer each question now.*

1. Process Knowledge: How familiar are you with the group deliberation process known as Interactive Management?

    a. I know nothing about the process _____
    b. I know something about the process, but would not feel comfortable trying to explain it to someone else _____
    c. I think I could explain how the process works, after a brief refresher _____
    d. I can explain how the process works right now _____

2. Product Knowledge: How familiar are you with the products produced through the group deliberative process known as Interactive Management?

    a. I know nothing about the products _____
    b. I know something about the products, but would not feel comfortable trying to explain them to someone else _____
    c. I think I could explain what the products are, after a brief refresher _____
    d. I can explain what the products are right now _____

3. Training: Briefly describe any training you may have had with the Interactive Management process and/or its products.

4. Experience: Briefly describe any experience you may have had with the Interactive Management process and/or its products.

This survey is part of an ongoing effort to increase the usefulness of certain graphical displays intended to aid in the management of complexity. The general class of display under study is the Interpretive Structural Model (ISM). These models help viewers quickly grasp the essential aspects of a complex situation. The models are developed during a group deliberative process that has been given the name Interactive Management (IM).

The survey instrument you are now reading focuses on an interpretive structural model called a *problematique*. The *problematique* is intended to facilitate problem definition. It is often the first model to be developed in the IM process. Other interpretive structural models are aimed at identification of alternative solutions to the problem, selection of the preferred alternative, and development of an implementation plan. Those IM products have been given the names *option field*, *priority structure*, and *resolution structure* to reflect their purpose.

Before proceeding to the survey itself, we ask that you read the following material concerning the process by which the problematique is developed and some important clues to understanding what it means and does not mean.

The Development Process

The problematique is developed during an IM session in a two-phase process. During the first phase, participants, selected for their technical knowledge or interest in the problem under review, respond to a *trigger* question posed by the session's sponsor. A typical trigger question takes the following form:

> "What are the critical factors which inhibit the
> ability to meet objective X?"

Participants are not limited in the number of responses they generate. The intent is to avoid premature closure by encouraging open dialogue and suppressing individualized agendas. Each response is recorded, numbered for tracking purposes, and discussed to assure understanding. Past experience suggests that hundreds of responses can be generated during this phase of an IM session. The first phase concludes with each participant selecting five factors that merit immediate further processing. There tends to be very little duplication in this selection process. Thus, the total number of items to be analyzed depends upon the number of participants.

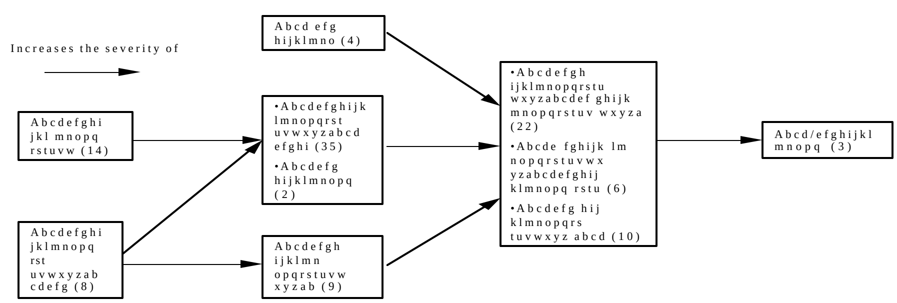
The second phase of problematique development involves a pair-wise comparison of this initial set of responses to establish their relationship with each other. The comparison is made in response to a *generic* question, also selected by the session's sponsor, which might take the following form:

“ In the context of improving the ability to meet
objective X, does element A significantly increase
the severity of element B?”

A second and third set of factors may be selected for inclusion in the pair-wise comparison depending upon the time available and the group’s desire to expand the resulting model. Past experience suggests that one to three iterations is sufficient to identify those problem elements that the group feels are sufficiently important enough to warrant immediate attention. Thus, the resulting problematique displays some, *but not all*, elements impacting the problem under consideration. In addition, the problematique displays only *one* form of relationship among those elements--the one considered most critical by the sponsor of the IM session. By way of analogy, think of a problematique as a snapshot. What we see reflects what the photographer thought was important. We do not know what was missed when the camera shutter went click!

An example of a problematique is shown below and is followed by some hints to help you interpret its meaning. We have used nonsensical statements in this example to help you focus on the model’s logic and format. *Understanding the meaning of the model does not require knowledge of its content.*

The Problematique

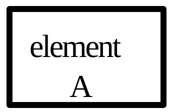


The Meaning of Structure

Prior research has shown that most English speaking readers will automatically begin “reading” visual material from left to right and from top to bottom. They may even experience noticeable mental discomfort when forced to follow a logic that unfolds in the opposite direction. This natural tendency can lead to erroneous presumptions about the meaning of information in a visual display.

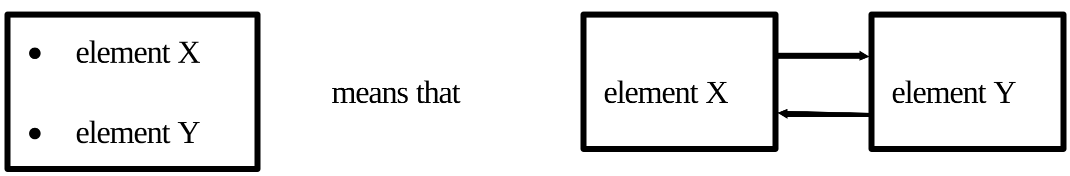
1. The basic building blocks of the problematique are:

a. The *boxes* that contain problem elements. The size and shape of each box have no significance:



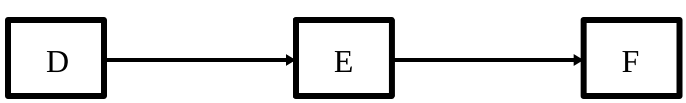
b. The *arrow* shows the direction of the relationship being portrayed. That relationship is one of influence, not causality:

c. When two or more problem elements influence each other, they are bulletized and placed within the same box to simplify the problematique's display. Such a combination of elements is called a *cycle*:

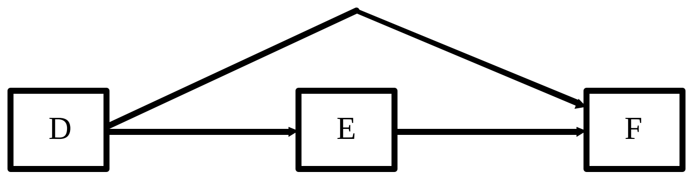


The elements in a cycle *must* be addressed collectively if their influence on each other and on any other elements is to be resolved effectively.

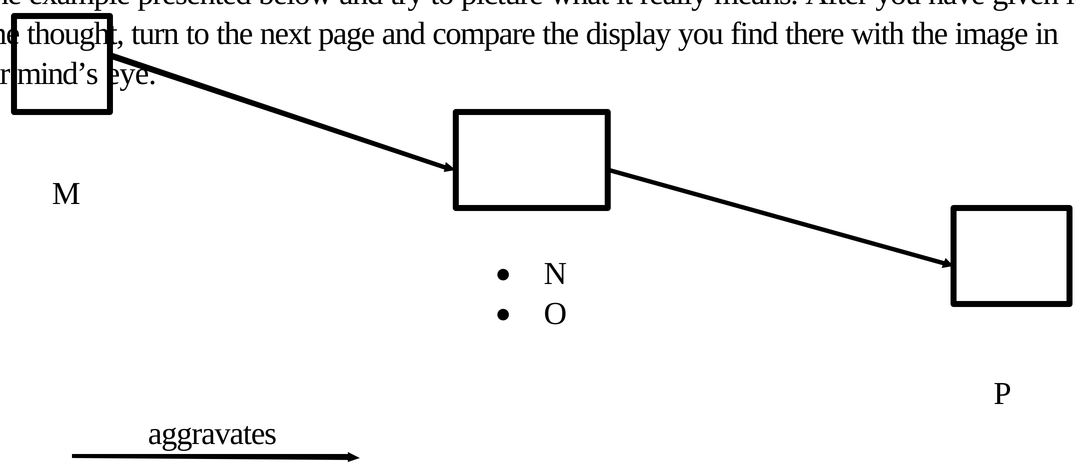
2. The relationship that is portrayed in a problematique is both transitive and propagating. The concept of propagation is relatively clear. It means that the negative impact grows as one moves along the path indicated by arrows connecting problem elements. The display below indicates that the problem element F is more severe due to the negative influence of element E which, in turn, is more severe due to the negative influence of element D.



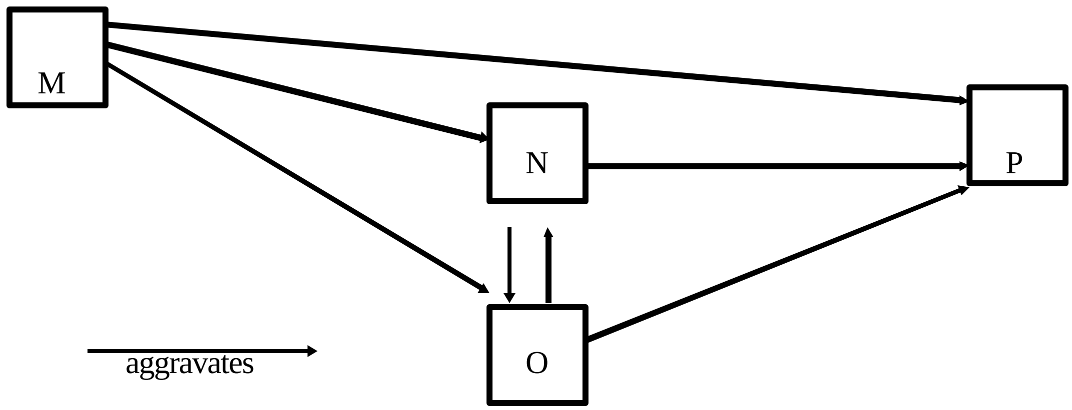
The concept of transitivity is best portrayed by the following display since, in a transitive relationship, if element E were to be completely resolved, element F would still be negatively influenced by element D.



Given the foregoing guidance for understanding the meaning and logic of a problematique, look at the example presented below and try to picture what it really means. After you have given it some thought, turn to the next page and compare the display you find there with the image in your mind's eye.



When you have a picture of the relationships in mind, place a check mark here ____ and turn the page.



This is what the structure of the problematique on the previous page means.

Was this what you pictured in your mind's eye? YES ______ NO ______

If you answered NO, which links did you miss?

_____ M to P
_____ M to N
_____ M to O
_____ N to P
_____ N to O
_____ O to N
_____ O to P

What the structure does not contain

Keep in mind that the purpose of a problematique is to display, as simply as possible, the interrelationships found in complex problems.

1. A problematique shows only one relationship among the elements of the problem although it is the relationship which is believed to make matters worse. The elements that are included are only those that the group feels important enough to merit immediate attention. There may be additional elements that the group has not identified, even though hundreds of elements may have been generated during the idea generating phase of the Interactive Management session. We don't know from looking at the problematique where those other elements would be placed if put to the pair-wise comparison test.

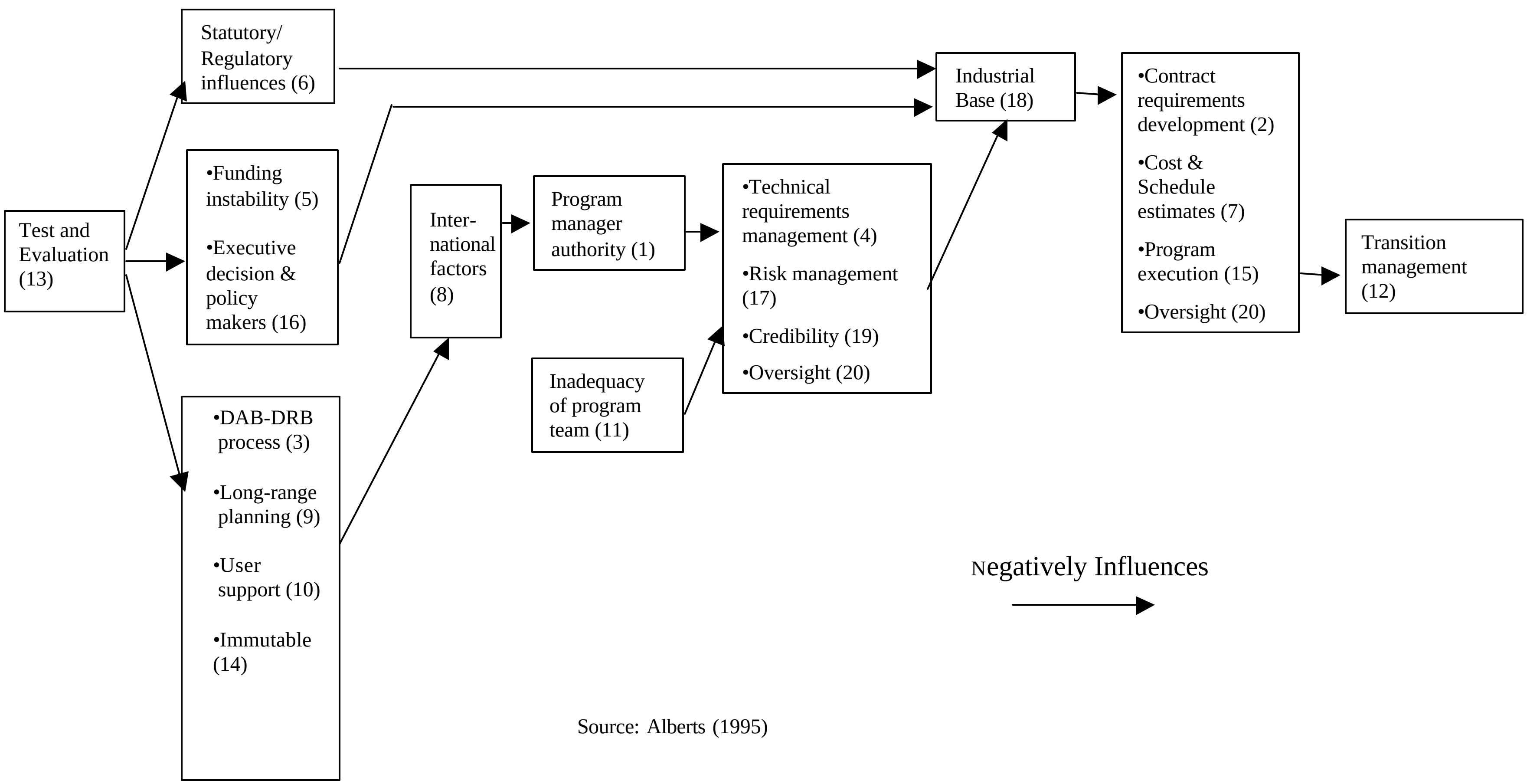
2. Neither do we know which problem elements should be addressed first nor how long any of them might take to resolve since those questions are not addressed in the process used to develop a problematique. While there is some logic to attributing greater influence to elements on the left as opposed to those on their right, such an assumption must be treated as a hypothesis subject to verification. Likewise, while it may be logical to assume that elements to the right in a problematique may have more factors influencing them than elements to their left, there is no basis for any assumption concerning the length of time it will take to resolve them. In other words, based on the problematique alone, one might hypothesize, but cannot conclude that the leftmost elements deserve some higher priority of attention and that rightmost elements will take longer to resolve. Such hypotheses require further investigation.

3. Finally, the numbers in parentheses following each element indicate the sequence in which elements were presented by the workshop participants. They are retained for tracking purposes only and have no other connotation. While a lower number would indicate that an idea came to mind earlier in an IM session, past experience suggests that such ideas may not be fundamental to the problem situation. In other words, the IM process facilitates uncovering factors that may be critical to problem definition and resolution, but easily overlooked under a less rigorous structuring process. *The problematique with its focus on problem definition is only the first step in the process required to resolve truly complex problems.*

The following pages contain questions regarding a problematique that has influenced the course of acquisition reform. A clear understanding of its meaning may help you to better grasp the intent of policy changes currently being implemented within the federal government. Please answer the questions we pose to the best of your ability. Providing an explanation of the reasoning behind your selection of an answer, when requested, will be most beneficial in our efforts to make Interactive Management products more user friendly.

Thanks for your help.

Problematique displaying negative influences among selected acquisition process problem categories



Source: Alberts (1995)

Please provide brief answers to the following questions based solely on your own interpretation of the problematique being displayed.

1. T___ or F___ This problematique contains four *cycles*.

2. T___ or F___ The problem categories Funding Instability (5) and Executive Decision & Policy Makers (16) must be treated collectively if their negative influence is to be alleviated.

3. Which of the following problem categories should be addressed first? (choose one)
   - _____ a. Test and evaluation (13)
   - _____ b. Inadequacy of program team (11)
   - _____ c. Transition management (12)
   - _____ d. None of the above

Please explain the reason for your answer:

4. Which of the following elements will take longer to resolve? (choose one)
   - _____ a. Funding instability (5) and Executive decision & policy makers (16)
   - _____ b. Technical requirements management(4), Risk management (17), Credibility (19), and Oversight (20)
   - _____ c. Test and evaluation (13)
   - _____ d. None of the above

Please explain the reason for your answer:

5. Resolving Technical requirements management(4), Risk management (17), Credibility (19), and Oversight (20)will completely eliminate the impact of? (choose one)

______ a. Program manager authority (1)
______ b. Inadequacy of program team (11)
______ c. Industrial base (18)
______ d. None of the above

Please explain the reason for your answer:

6. The *cycle* that consists of DAB-DRB Process (3), Long-range planning (9), User support (10), and Immutable [problems](14) negatively influences International factors (8), which in turn negatively influences Program manager authority (1).

______ I strongly agree
______ I agree somewhat
______ I have no opinion
______ I somewhat disagree
______ I strongly disagree

Please explain the reason for your opinion:

7. The problem category Statutory/Regulatory Influences (6) is one of the primary causes for the problem category Industrial Base (18).

______ I strongly agree
______ I agree somewhat
______ I have no opinion
______ I somewhat disagree
______ I strongly disagree

Please explain the reason for your opinion:

8. This problematique proves that reducing Oversight (20) will improve the acquisition process.

______ I strongly agree
______ I agree somewhat
______ I have no opinion
______ I somewhat disagree
______ I strongly disagree

Please explain the reason for your opinion:

9. The best way to resolve problems with the acquisition process is to start with Transition management (12) and work back toward Test and Evaluation (13) to find and fix the fundamental causes.

______ I strongly agree
______ I agree somewhat
______ I have no opinion
______ I somewhat disagree
______ I strongly disagree

Please explain the reason for your opinion:

10. How would you rate the display you have been viewing as a briefing aid to support discussions with your boss?

______ Extremely useful
______ Very useful
______ I have no opinion
______ Not very useful
______ Totally useless

Please explain the reason for you opinion:

11. What is the meaning of the relationships portrayed by the arrow?

12. What is the managerial implication, if any, when multiple elements occupy the same box.? What is the basis for your conclusion?

13. How would resolution of elements on the left impact those to their right?

14. Which element(s) do you feel should be addressed first and why? (use the parenthetical numbers to indicate which element(s) you are choosing)

15. Which element(s) do you feel will require more effort to resolve and why? (use the parenthetical numbers to indicate which element(s) you are choosing)

16. Given what you see in the problematique, what do you feel is the next appropriate step or steps to take in resolving the situation portrayed?

Appendix B

Managerial Assumptions about the Nature of Complexity

Overview

This study focused on participant opinions regarding the nature of complexity. John N. Warfield (1998) identified a series of assumptions he believes people make about the nature of complexity. He feels these assumptions interfere with the effective management of large-scale problematic situations to such a degree that he has labeled them as "killer assumptions." Warfield also identified a series of demands that complexity places on management. The demands of complexity are the antithesis of the killer assumptions. The purpose of this research effort was to assess how widely each, if any, of the killer assumptions might be held among individuals responsible for managing the acquisition and life-cycle support of national defense systems. This study included over 100 highly schooled engineering- and management-oriented acquisition professionals associated with a course in systems acquisition management at the Defense Systems Management College (DSMC) and was completed in December 1998.

Analysis of responses to questionnaires revealed significant optimism among both course attendees and faculty regarding human learning powers regardless of the scale of the learning task and considerable belief that complexity is intrinsic to a system under observation. The results indicate a pressing need to train managers to respect the demands of complexity. Fulfilling this need will be difficult so long as academicians continue to overestimate human cognitive ability to contend with large-scale problematic situations.

Statement of the Problem

Defense system acquisition involves the interaction of multiple organizations, both public and private, as well as multiple functions within those programs. Defense system acquisition programs cost American taxpayers billions of dollars each year and are frequently beset with large-scale problematic situations. Failure to recognize the unique requirements for dealing with complexity when faced with such situations often leads to unanticipated outcomes that further complicate matters within both the public and private sectors.

Background

John N. Warfield (1998) identified a series of assumptions he believes people make about the nature of complexity. He feels these assumptions interfere with the effective management of large-scale problematic situations to such a degree that he has labeled them as "killer assumptions." Warfield identified seven attributes of a killer assumption. They are listed below:

- Its impact is widespread.
- It limits the capacity of people to perform in problematic situations.
- It diminishes significantly the quality of what people produce in problematic situations.
- It is held on a grand scale by very large numbers of people.
- It works against its corrective replacements whenever and wherever they are proposed in regard to complexity.

- It is given status by its continuance as part of what is propagated in academic institutions, whose offerings are mostly indifferent to the demands of complexity.
- It is usually valid in normal situations, but it has no validity when complexity is involved.

Warfield also identified a series of demands that complexity places on management. The demands of complexity are the antithesis of the killer assumptions.[1]

Research Question

The purpose of this study was to assess how widely each, if any, of the killer assumptions might be held among individuals responsible for managing the acquisition and life-cycle support of national defense systems. Results of such an assessment should help focus the attention of academicians and practitioners on the need to respect the demands of complexity when managing the problematic situations encountered during the system acquisition process.

Research Design

A research design based on non-random purposive sampling techniques was adopted in an effort to obtain a sufficient number of survey responses from which to draw useful information. Self-administered questionnaires were used to gather data. Non-parametric statistical analysis as suggested by Siegel & Castellan (1988) was selected as the most appropriate procedure for analyzing the data. Use of non-random purposive sampling techniques permit us to describe what was discovered, but not to state generalizable conclusions concerning the associations or patterns uncovered. This

[1] A list of killer assumptions and demands of complexity are at appendix B-1.

restriction was deemed acceptable since participant demographics generally reflect the composition of the U. S. defense acquisition workforce.

Research Participants

Participants included highly schooled engineering- and management-oriented acquisition professionals associated with the Advanced Program Management Course (APMC), an intensive 14 week course in systems acquisition management presented by the Defense Systems Management College (DSMC) located at Fort Belvoir, VA. The college is considered to be the premier center for learning about the Department of Defense systems acquisition process. Successful completion of the course is considered essential for selection as a program manager of a major defense system acquisition program. These individuals represent a group of public and private sector decision-makers faced with managing the acquisition and life cycle support of U.S. Department of Defense (DoD) systems costing American taxpayers billions of dollars. Virtually all survey respondents had four or more years of college education. Most held undergraduate and higher degrees in an engineering or business discipline. Many had several year's experience in the field of systems acquisition management before coming to DSMC. These individuals and the society they serve would benefit greatly from an understanding of the demands of complexity.

Research Method

A set of four questionnaires was used to gather comparative data from one group of faculty and three groups of course attendees. Seventeen questions were posed in each instrument. Each question required the respondent to choose between a statement expressing one of Warfield's killer assumptions and another statement expressing its antithetical demand of complexity. Questions and statements within questions were reordered in three of the four instruments to minimize response bias.[2] Respondents were also asked to indicate how strongly they felt about their choices. One hundred thirteen responses were obtained from 28 faculty and 85 course attendees.

Results

Analysis of the data focused on three areas concerning killer assumptions: frequency of selection; strength of opinion concerning choices; and, patterns in individual responses.

Frequency of Selection

A listing of all 17 killer assumption statements, in descending order of selection is shown below. The percentages shown parenthetically before each statement reflect the proportion of individuals choosing the killer assumption from among those individuals who answered that particular question. The number in brackets following each statement indicates the order in which the particular question concerning complexity appeared in the first version of the questionnaire. This same number is retained throughout this appendix for purposes of identification and continuity.

- (61.6%) Complexity and Learning: Human learning powers are independent of the scale of what is to be learned. [2]
- (46.3%) The Site of Complexity: The site of complexity is in the system being observed. [1]

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[2] A copy of the first questionnaire used is at appendix B-2. Copies of the other three versions are available from the author.

- (44.3%) Complexity and Executive Capacity: The executive has the intellectual capacity to comprehend: [17]
    - All of the factors that are relevant to an executive decision.
    - How the various factors are interrelated in a problematic situation.
    - What alternatives are relevant when it is time to make a choice.
    - How to prioritize the alternatives.
    - At what time action should be initiated.
- (43.5%) Complexity and Linguistic Infrastructure: Natural language is adequate to represent complexity. [13]
- (36.5%) Complexity and Representational Infrastructure: Representation of complexity through metaphors related to common quantitative formalisms from physical sciences is strongly contributory to the resolution of complexity. [10]
- (29.8%) Complexity and Workplace Infrastructure: There is no reason to provide any special infrastructure at work to deal with complexity. [14]
- (22.9%) Complexity and the Quality of Linguistic Infrastructure: Academics should be free to call any subject that they choose a “science” with no institutionally-established requirements and standards for linguistic quality control. [16]
- (22.9%) Complexity and Spatial Infrastructure: There is no need to allocate space specifically for the purpose of portraying complexity. [12]

- (22.8%) Complexity and Formalism Infrastructure: The extent of valid application of common quantitative formalisms from physical sciences into socio-technical arenas is very large, and can be organized so that it is almost automatic. [11]
- (21.3%) Complexity and Group Process Design: Normal processes are sufficient to enable description and diagnosis of problematic situations involving high complexity. [6]
- (21.2%) Complexity and Scientific Infrastructure: It is appropriate to discuss science and technology as though there are no essential distinctions between them. [15]
- (16.8%) Complexity and Process Design: There is no need for empirical evidence to justify assumptions of relevance when designing processes to support resolution of complexity. [4]
- (15.4%) Complexity and the Integration of Knowledge: Simple amalgamation of disciplines will relieve disciplinary shortcomings in considering comprehensive domains. [8]
- (13.7%) Complexity and Types of Relationships: There is seldom any reason to give the choice of types of relationships that are to be used in studies the same level of effort and depth of selectivity that are given to the elements that will be related (e.g. in model development). [9]
- (11.2%) Complexity and Behavioral Research Findings: The findings from behavioral science about individuals, groups, and organizations are too “soft” to have a major role in the management of organizations. [7]

- (5.4%) Complexity and Sources of Information: If information comes from a "prestigious" source, it need not be questioned. [5]
- (2.7%) Complexity and History: In high-technology environments of today, learning from history is largely irrelevant to organizational decision making. [3]

Table B1 displays the number of respondents choosing each alternative as well as the number of times respondents did not make a choice. The number in brackets indicates the order of presentation in the first questionnaire. That same numbering scheme is used throughout this paper for purposes of identification and continuity.

Table B1. The Choices Made About Complexity

The choices made by 113 respondents about Complexity and –	Killer Assumption	neither answer	Demand of Complexity
Learning [2]	69	1	43
The site of complexity [1]	50	5	58
Executive capacity [17]	47	5	61
Linguistic infrastructure [13]	47	7	59
Representational infrastructure [10]	38	9	67
Workplace infrastructure [14]	31	9	73
The quality of linguistic infrastructure [16]	24	8	81
Spatial infrastructure [12]	24	8	81
Formalism infrastructure [11]	23	12	78
Group process design [6]	23	5	85
Scientific infrastructure [15]	22	9	82
Process design [4]	18	6	89
The integration of knowledge [8]	16	9	88
Types of relationships [9]	14	10	89
Behavioral research findings [7]	12	6	95
Sources of information [5]	6	1	106
History [3]	3	1	109
Totals	466	111	1344
Percentages	24.3%	5.8%	69.9%

Respondents chose statements concerning the demands of complexity over those expressing Warfield's killer assumptions most of the time. However, killer assumption statements were chosen, on average, almost 25% of the time, indicating that their potential role in the mismanagement of problematic situations is not trivial.

Figure B1 graphically displays the percentage of respondents choosing between a killer assumption statement and its antithetical demands of complexity statement.

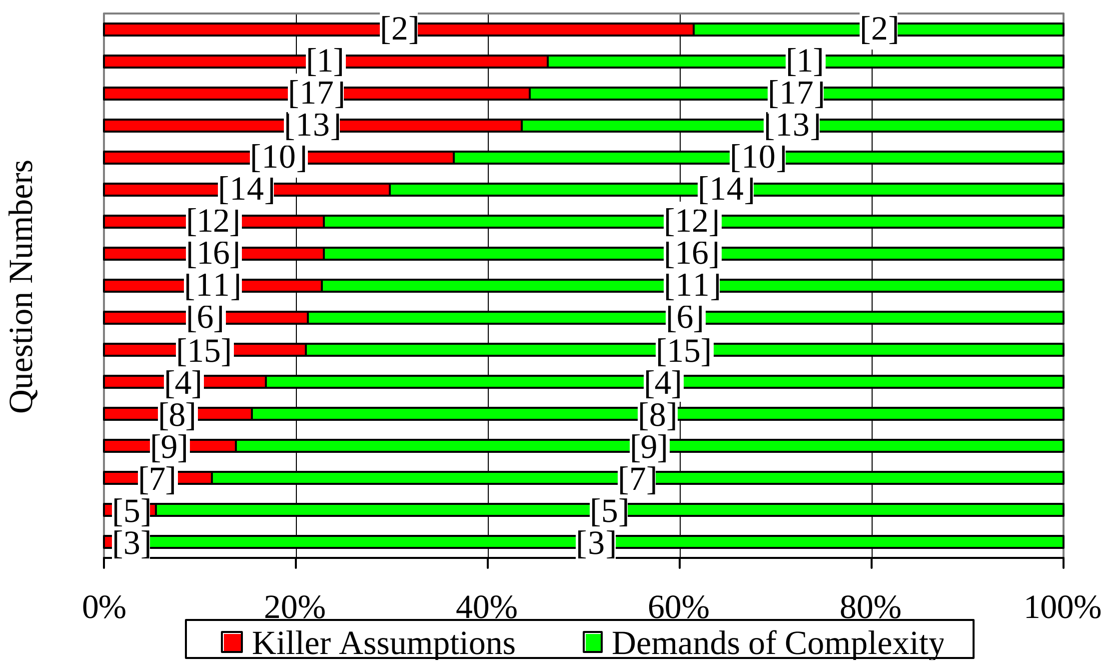


Figure B1. Percentage of Respondents Choosing Between Killer Assumptions and Demands of Complexity Statements

Figure B1 shows that some of the killer assumptions appealed to far more respondents than others. For example, four of the 17 killer assumption statements were picked by over 40% of the respondents. One of those appealed to more than 60% of the individuals able to make a choice between the two alternatives. Seven of the remaining thirteen killer assumptions were chosen by 20% to 40% of the respondents. Only two of 17 killer assumptions were selected by less than 10% of the respondents.

Figure B2 displays the total number of killer assumption statements chosen by individual respondents. Totals ranged from a low of zero to a high of 14.

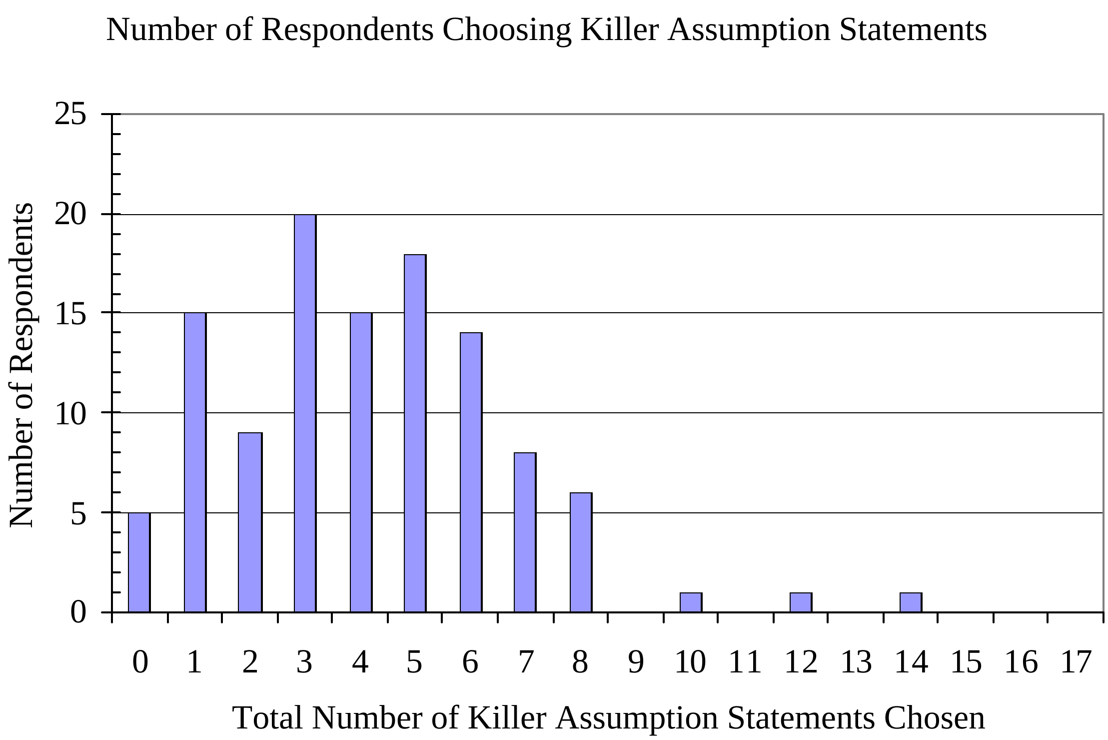


Figure B2. Total Number of Killer Assumption Statements Chosen by Respondents

The most frequent number of killer assumption statements chosen by any one respondent was three. The average number chosen was four. We then compared the number of killer assumptions chosen by faculty versus the number chosen by attendees. The results are displayed in Figure B3.

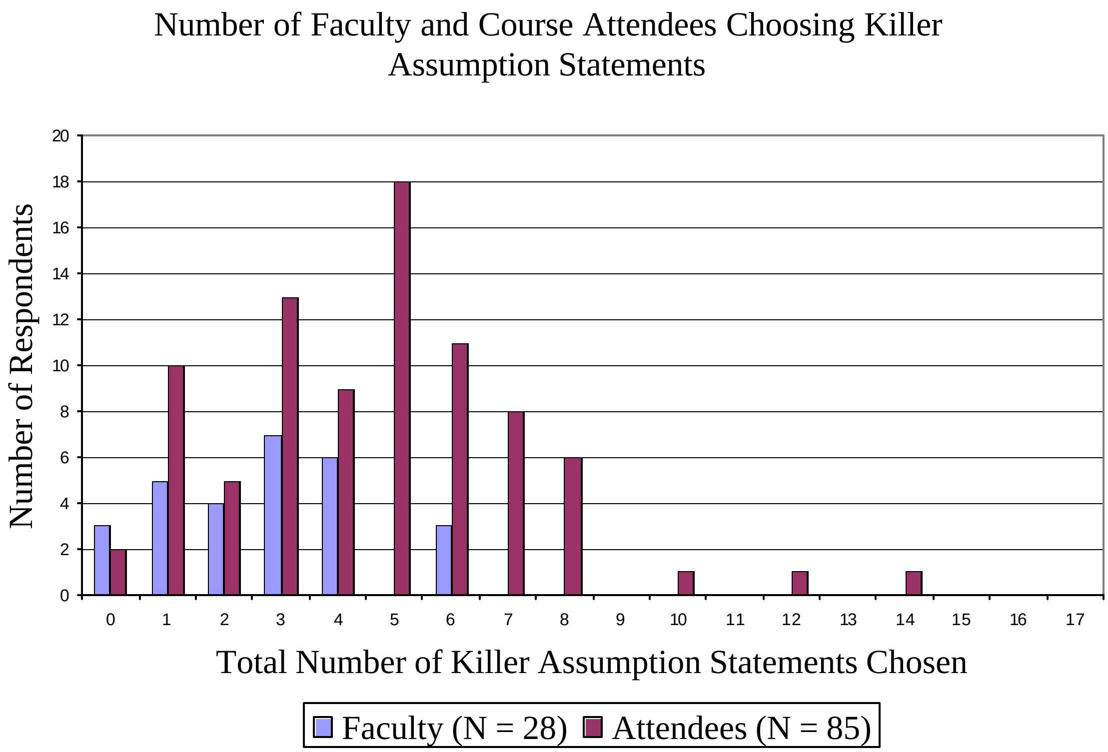


Figure B3. Number of Killer Assumptions Statements Chosen By Acquisition Professionals

Our analysis showed that the most frequent number of killer assumption statements chosen by faculty was three. The maximum number of killer assumptions chosen by any one faculty member was six. The most frequent number chosen by course attendees was five and the maximum number of statements chosen was 14. Choices made among killer assumptions by faculty and attendees were then compared. The differences are displayed in Figure B4.

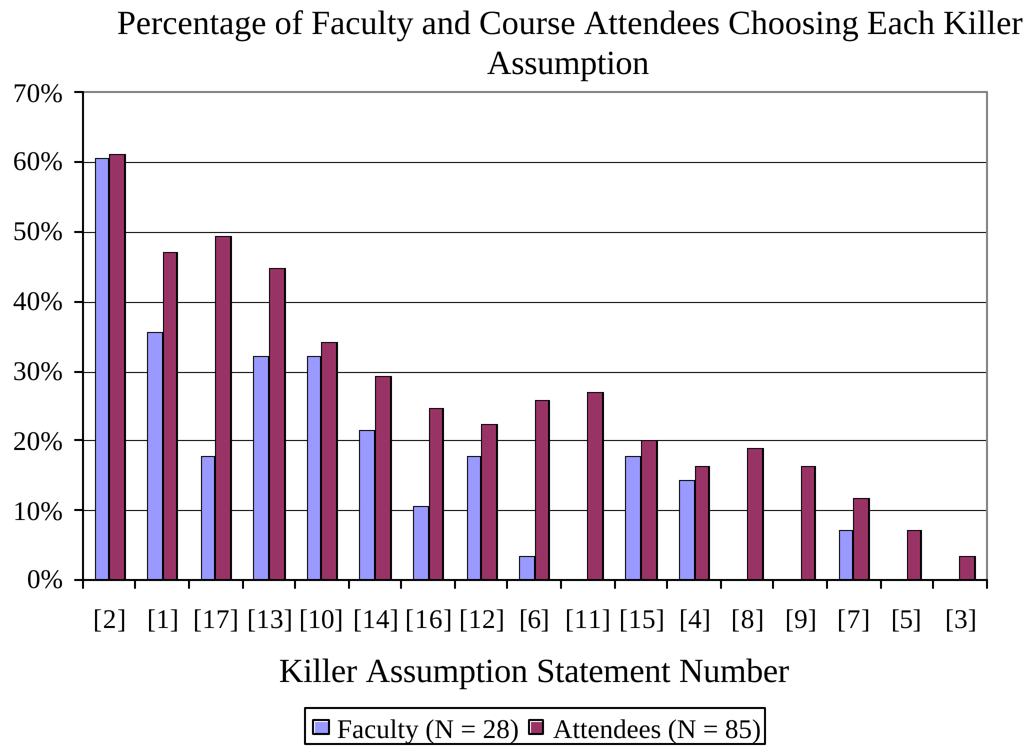


Figure B4. Percentage of Acquisition Professionals Choosing Each Killer Assumption Statement

Our analysis showed that the faculty did not select all 17 killer assumption statements and that the percentage of faculty choosing a killer assumption statement was always lower than the APMC attendee percentage. These differences are encouraging. However, over 60% of both faculty and attendees agreed with the killer assumption statement that human learning powers are independent of the scale of what is to be learned [2]. The high selection rate may be due to the research being conducted at an educational institution, but it does raise a danger signal that overconfidence in human cognitive ability may be a significant barrier to successful management of complexity. Failure among faculty to recognize the demands of complexity relative to learning could lead to insufficient emphasis on the subject during curriculum design. Failure among course attendees to recognize that individuals cannot resolve complexity simply by thinking about it or addressing it in unorganized group discussions could lead to repeated failures when they encounter problematic situations back on the job.

Strength of Opinion about Choices

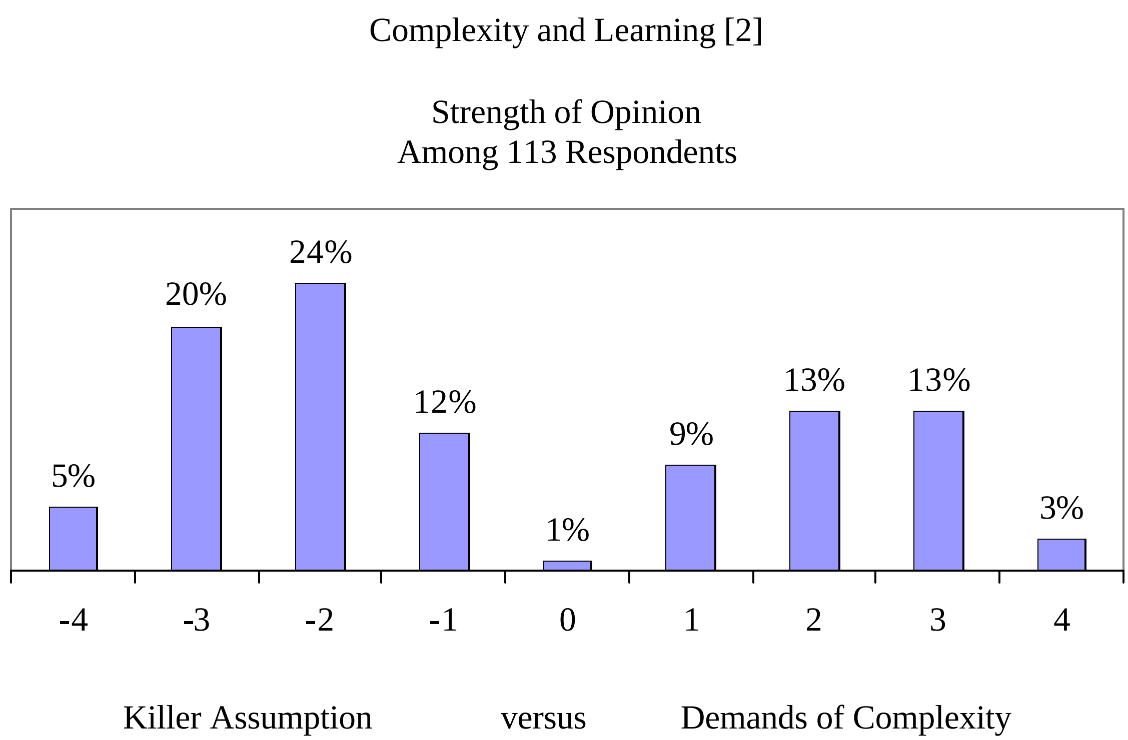
Our second area of analysis attempted to identify how strongly the respondents felt about their choices among killer assumptions and the demands of complexity. Analysis of all respondents' opinions about their choices disclosed that 30% or more held strong opinions about their selection of the four most frequently picked killer assumptions. The breakout of opinions for those four are shown in figures B5 through B8. Similar displays for the other 13 choices are contained in Appendix B-3. When reviewing the displays, keep in mind that participants had been asked to indicate the strength of opinion about their choices using the following *Likert*-type scale:

4 = Extremely strongly
3 = Very strongly
2 = Somewhat strongly
1 = Not at all strongly

We assigned a negative sign to opinions about killer assumption choices to indicate the impact on problem resolution.

Figure B5 shows the strength of opinions held about responses to the following dichotomy:

- Killer Assumptions: Human learning powers are independent of the scale of what is to be learned. (Chosen by 69 respondents.)
- Demands of Complexity: Individuals cannot resolve complexity simply by thinking about it or discussing it in unorganized group conversations. (Chosen by 43



respondents.)

Figure B5. Strength of Opinion about Complexity and Learning

The display indicates that 12% of 113 respondents chose the killer assumption statement, but did not feel at all strongly about that choice. Twenty four percent felt somewhat strongly about their choice. Twenty percent felt very strongly, while 5% felt extremely strongly about their choice of the killer assumption statement. Conversely, nine percent of the 113 respondents selected the demands of complexity statement, but did not feel at all strongly about that choice. Twenty six percent were split equally between a somewhat and a very strongly felt opinion. Only three percent felt extremely strongly about their choice. The reader in a similar fashion should interpret figures B6, B7, and B8.

Figure B6 displays respondents' strength of opinion about the following dichotomy:

- Killer Assumption: The site of complexity is in the system being observed. (Chosen by 50 respondents.)
- Demands of Complexity: The complexity of a situation is distribute among many minds (Chosen by 58 respondents.)

Figure B6. Strength of Opinion about the Site of Complexity

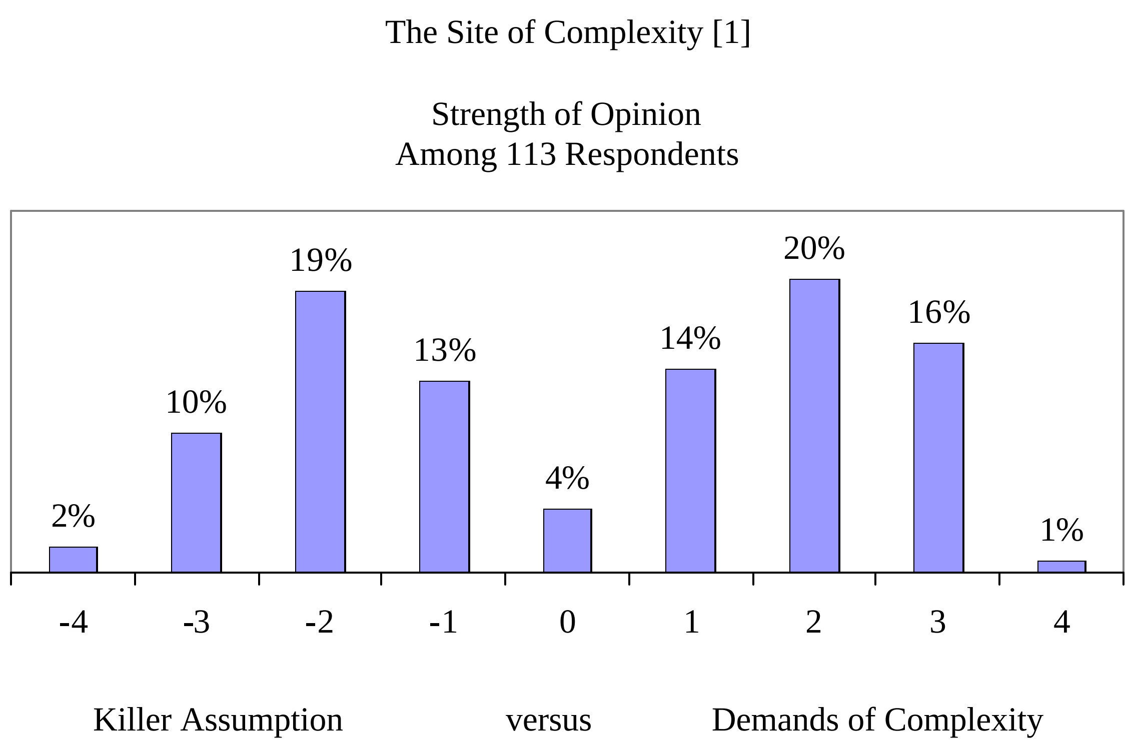


Figure B7 displays strengths of opinion about the following dichotomy:

- Killer Assumption (Chosen by 47 respondents): The executive has the intellectual capacity to comprehend:
  - All of the factors that are relevant to an executive decision.
  - How the various factors are interrelated in a problematic situation.
  - What alternatives are relevant when it is time to make a choice.
  - How to prioritize the alternatives.
  - At what time action should be initiated.
- Demands of Complexity: Complexity demands that organizations accept the inevitability of executive inadequacy to resolve complexity, as an inherent property of every human being. (Chosen by 61 respondents.)

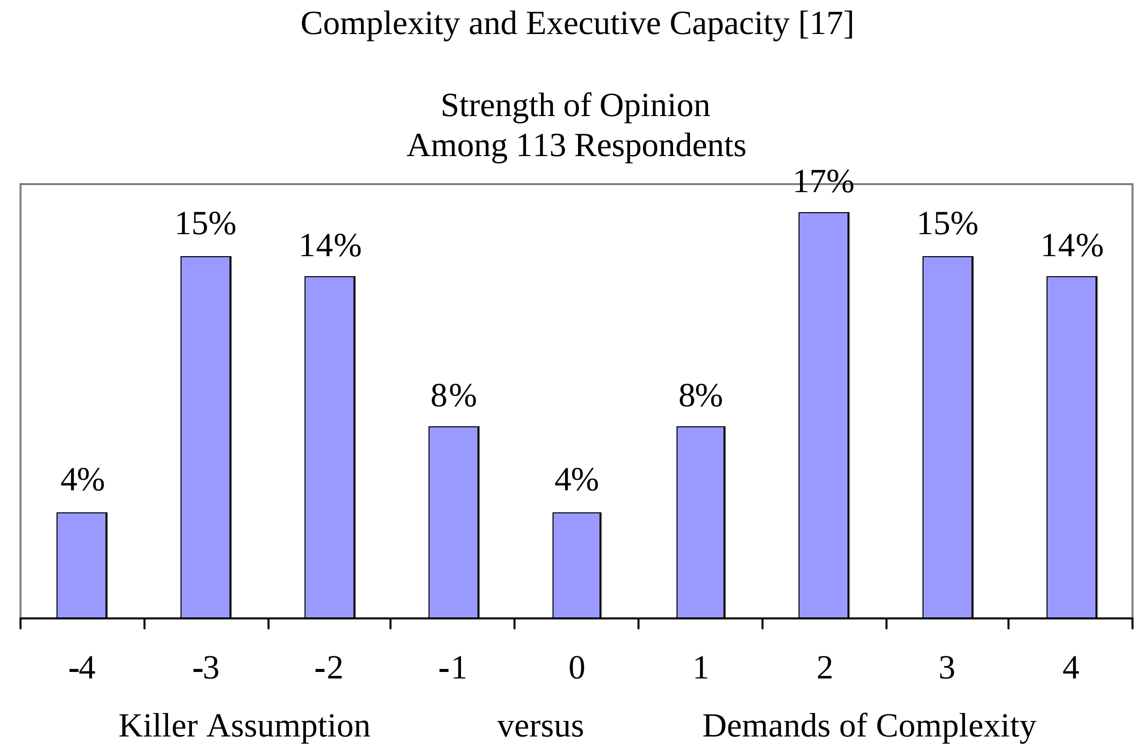


Figure B7. Strength of Opinion about Complexity and Executive Capacity

Figure B8 displays respondents' strength of opinion about the following dichotomy:

- Killer Assumptions: Natural language is adequate to represent complexity. (Chosen by 47 respondents.)
- Demands of Complexity: The inadequacy of natural language (e.g. linearity) must be recognized; graphical nonlinear logic must be widely adopted in the domain of complexity to help overcome that inadequacy. (Chosen by 59 respondents.)

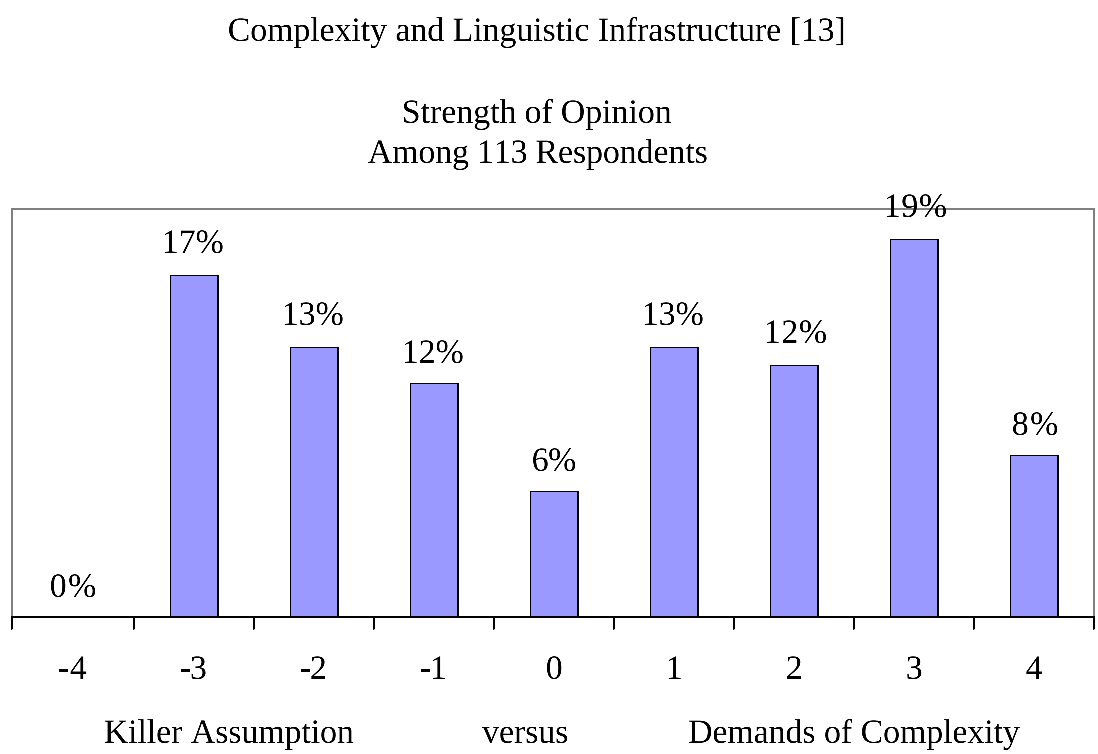


Figure B8. Strength of Opinion about Complexity and Linguistic Infrastructure

We also compared strength of opinion about the four most frequently chosen killer assumption statements among DSMC faculty and APMC attendees. The results are displayed in Figure B9.

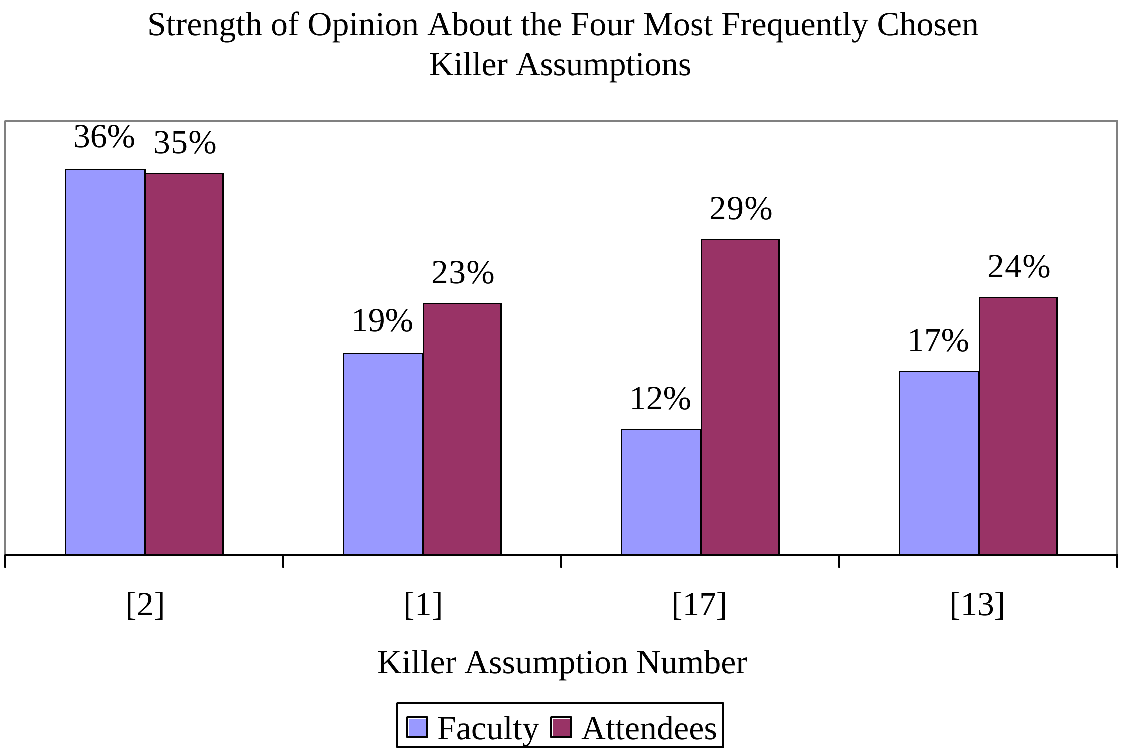


Figure B9. Acquisition Professional's Strength of Opinion About the Four Most Frequently Chosen Killer Assumption Statements

The percentages shown in Figure B9 are best understood as follows. If all 28 faculty felt extremely strongly about a killer assumption statement, that statement would have received a maximum score of 112 (4 x 28 = 112). The actual sum of all scores for killer assumption number two [2] among the faculty was 40, which when divided by 112 is equal to 36%. The maximum possible score attributable to any killer assumption statement by course attendees was 340 (4 x 85 = 340). The actual sum of all scores for killer assumption number two [2] among the course attendees was 120, which when divided by 340 was equal to 35%. The other percentages were calculated in like fashion. Normalizing the strength of opinion scores in this fashion provided insight to differences in faculty and APMC attendee opinions about the four most frequently chosen killer assumption statements.

As Figure B9 indicates, both faculty and course attendees felt about the same concerning killer assumption statement [2] that human learning powers are independent of the scale of what is to be learned. Faculty strength of opinion concerning killer assumption statement [1] that the site of complexity is in the system being observed was not as strong as the course attendees' strength of opinion. There was quite a bit of difference between faculty and attendee opinion concerning killer assumption statement [17] regarding the intellectual capacity of executives. Faculty strength of opinion concerning killer assumption statement [13] that natural language is adequate to represent complexity was also somewhat less than the attendees' strength of opinion. When viewed from another perspective, faculty strength of opinion concerning the site of complexity [1] and natural language [13] was about half as strong as their opinion about human learning power [2] and belief in the intellectual capacity of executives [17] was about one third as strong. Course attendee strength of opinions about all four statements were much closer together in degree.

Patterns of Choices

Our third area of analysis focused on patterns among respondents' choices. We looked for paired choices of killer assumption statements. Not surprisingly, we found that most pairings occurred among the four most frequently chosen statements. Figure B10 shows how 113 respondents paired the four most frequently chosen killer assumptions. We also compared pairings of the four killer assumptions by faculty and course attendees. The results of our analysis are shown in Table B2.

Table B2. Proportion of Faculty and Course Attendees Pairing Each of the Four Most Frequently Chosen Killer Assumption Statements.

Paired Statements	% of Faculty	% of Course Attendees
[2] and [1]	25%	32%
[2] and [13]	18%	32%
[2] and [17]	14%	29%
[13] and [17]	14%	27%
[13] and [1]	7%	24%
[17] and [1]	7%	27%

Figure B10. Four Most Frequently Paired Killer Assumptions

Discussion

This study was aimed at identifying which, if any, of Warfield's 17 killer assumptions might be widely held among individuals responsible for management of large-scale problematic situations. The participants in this effort represent a group of extremely dedicated and well-educated federal government employees responsible for managing the acquisition and life cycle support of national defense systems costing billions of taxpayer dollars. That task is often subject to enormous political and economic pressures that compound and confound what is already a significantly challenging systems management activity. To underestimate the demands of complexity in such situations is tantamount to an open invitation for failure.

The results of this study indicate that quite a few participants did lack an appreciation for the demands of complexity, thus lending support for Warfield's hypothesis concerning the extent to which the killer assumptions underlie the mismanagement of problematic situations. Forty percent or more of the respondents chose the same four killer assumption statements--the essence of which suggest that resolution of large-scale problems presents no unique challenge. The two most frequently combined killer assumptions were that complexity is in the system being observed and that human learning powers are independent of what is to be learned. This is worrisome as it indicates that overcoming cognitive barriers to the management of problematic situations will be a daunting task. Conversely, strength of opinions held about the other 13 killer assumptions was not very high. Perhaps, there will be less resistance to changing opinions regarding the demands of complexity in those areas.

It was also encouraging to find that faculty were not as likely to choose killer assumption statements as were the course attendees. However, it would be unwise to discount the importance of Warfield's hypothesis that educational institutions fail to prepare students to deal adequately with the demands of complexity (Warfield, 1997.) This is particularly so given the apparent level of faculty confidence in human cognitive abilities. Over 60% of the faculty participants in this study agreed with the statement that human learning powers are independent of the scale of what is to be learned. Yet, there is abundant evidence in scholarly literature and the popular press to argue against overconfidence in humanity's ability to satisfactorily resolve large-scale socio-technical problems. The inability of the human mind to process more than a few bits of information simultaneously is well known (Miller, 1956; Simon, 1974; Warfield, 1988). The resulting tendency is to under-conceptualize complexity, thereby avoiding cognitive overload.

Conclusions

Analysis of responses to questionnaires revealed a substantial lack of awareness concerning the nature of complexity. Over 60% of the APMC attendees and faculty agreed with the statement that human learning powers are independent of the scale of what is to be learned. Three other killer assumptions were favored by 40% or more of the participants. Fifteen of the killer assumption statements were chosen by more than 10% of the respondents. These results indicate a pressing need to train acquisition professionals to respect the demands of complexity, yet fulfilling this need will be difficult so long as academicians and practitioners continue to overestimate human cognitive ability to contend with large-scale problematic situations.

Appendix B-1

Killer Assumptions and their Antithetical Demands of Complexity

Killer Assumptions	Demands of Complexity
The site of complexity is in the system being observed. [1]	The complexity of a situation is distributed among many minds.
Human learning powers are independent of the scale of what is to be learned. [2]	Individuals cannot resolve complexity simply by thinking about it or discussing it in unorganized group conversation.
In high-technology environments of today, learning from history is largely irrelevant to organizational decision making. [3]	The lessons of history must be recognized and incorporated in learning situations.
There is no need for empirical evidence to justify assumptions of relevance when designing processes to support resolution of complexity. [4]	Scientifically respectable evidence must be applied in designing processes to support resolution of complexity.
If information comes from a "prestigious" source, it need not be questioned. [5]	The authority of "prestigious institutions" must be tested against the scientific base that ought to be provided to support that authority.
Normal processes are sufficient to enable description and diagnosis of problematic situations involving high complexity. [6]	The design of group processes must suit the character of complexity, rather than simply using conventional processes or allowing NO process design.
The findings from behavioral science about individuals, groups, and organizations are too "soft" to have a major role in the management of organizations. [7]	Linkages between thought leaders from the past and practices invoked in organizations must be widely understood, and taken into account in self-regulation of human behavior.
Simple amalgamation of disciplines will relieve disciplinary shortcomings in considering comprehensive domains. [8]	Interdisciplinary programs must be designed to meet complexity's demands for learning efficacy.

Killer Assumptions	Demands of Complexity
There is seldom any reason to give the choice of types of relationships that are to be used in studies the same level of effort and depth of selectivity that are given to the elements that will be related (e.g. in model development). [9]	In problematic situations, the choice of relationships to be applied shall have as much prominence in the thinking of practitioners as does the choice of elements that are to be related.
Representation of complexity through metaphors related to common quantitative formalisms from physical sciences is strongly contributory to the resolution of complexity. [10]	Complexity demands portrayal of the logic underlying the problematic situation.
The extent of valid application of common quantitative formalisms from physical sciences into socio-technical arenas is very large, and can be organized so that it is almost automatic. [11]	Advocacy of unvalidated metaphors of formalisms from physical science must be tempered; justification and empirical evidence must be provided to support such advocacy.
There is no need to allocate space specifically for the purpose of portraying complexity. [12]	Complexity demands that workspace allocation be designed especially to facilitate human learning.
Natural language is adequate to represent complexity. [13]	The inadequacy of natural languages (e.g., linearity) must be recognized; graphical nonlinear logic must be widely adopted in the domains of complexity to help overcome that inadequacy.
There is no reason to provide any special infrastructure at work to deal with complexity. [14]	A workplace infrastructure dedicated to resolving complexity would satisfy a major demand of complexity.
It is appropriate to discuss science and technology as though there are no essential distinctions between them. [15]	Complexity demands that technology used to help resolve problematic situations shall have been founded in science, and not just imposed by highly vocal advocates.

Killer Assumptions	Demands of Complexity
Academics should be free to call any subject that they choose a “science” with no institutionally-established requirements and standards for linguistic quality control. [16]	The word “science” must be restricted to those fields in which archival history, established laws, adequate empirical evidence, and adequate metrics have been established to form a science.
The executive has the intellectual capacity to comprehend: • All of the factors that are relevant to an executive decision. • How the various factors are interrelated in a problematic situation. • What alternatives are relevant when it is time to make a choice. • How to prioritize the alternatives. • At what time action should be initiated. [17]	Complexity demands that organizations accept the inevitability of executive inadequacy to resolve complexity, as an inherent property of every human being.

Appendix B-2

A Survey About The Nature Of Complexity

We are trying to find out what people think about the nature of complexity. Please take a few minutes to respond to the following questions. Thanks for your help.

* * * * * * * * * * * *

1.a. The site of complexity: **(choose only one)**

_____ (1) The site of complexity is in the system being observed.

_____ (2) The complexity of a situation is distributed among many minds.

1.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

1.c. Comments?

2.a. Complexity and learning: **(choose only one)**

_____ (1) Human learning powers are independent of the scale of what is to be learned.

_____ (2) Individuals cannot resolve complexity simply by thinking about it or discussing it in unorganized group conversation.

2.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

2c. Comments?

3.a. Complexity and history: **(choose only one)**

_____ (1) In high-technology environments of today, learning from history is largely irrelevant to organizational decision making.

_____ (2) The lessons of history must be recognized and incorporated in learning situations.

3.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

3.c. Comments?

4.a. Complexity and the process design: **(choose only one)**

_____ (1) There is no need for empirical evidence to justify assumptions of relevance when designing processes to support resolution of complexity.

_____ (2) Scientifically respectable evidence must be applied in designing processes to support resolution of complexity.

4.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

4.c. Comments?

5.a. Complexity and sources of information: **(choose only one)**

_____ (1) If information comes from a “prestigious” source, it need not be questioned.

_____ (2) The authority of “prestigious institutions” must be tested against the scientific base that ought to be provided to support that authority.

5.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

5.c. Comments?

6.a. Complexity and group process designs. **(choose only one)**

_____ (1) Normal processes are sufficient to enable description and diagnosis of problematic situations involving high complexity.

_____ (2) The design of group processes must suit the character of complexity, rather than simply using conventional processes or allowing NO process design.

6.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

6.c. Comments?

7.a. Complexity and behavioral research findings: **(choose only one)**

_____ (1)The findings from behavioral science about individuals, groups, and organizations are too "soft" to have a major role in the management of organizations.

_____ (2) Linkages between thought leaders from the past and practices invoked in organizations must be widely understood, and taken into account in self-regulation of human behavior.

7.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

7.c. Comments?

8.a. Complexity and the integration of knowledge: **(choose only one)**

_____ (1) Simple amalgamation of disciplines will relieve disciplinary shortcomings in considering comprehensive domains.

_____ (2) Interdisciplinary programs must be designed to meet complexity's demands for learning efficacy.

8.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

8.c. Comments?

9.a. Complexity and types of relationships: **(choose only one)**

_____ (1) There is seldom any reason to give the choice of types of relationships that are to be used in studies the same level of effort and depth of selectivity that are given to the elements that will be related (e.g. in model development).

_____ (2) In problematic situations, the choice of relationships to be applied shall have as much prominence in the thinking of practitioners as does the choice of elements that are to be related.

9.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

9.c. Comments?

10.a. Complexity and representational infrastructure: **(choose only one)**

_____ (1) Representation of complexity through metaphors related to common quantitative formalisms from physical sciences is strongly contributory to the resolution of complexity.

_____ (2) Complexity demands portrayal of the logic underlying the problematic situation.

10.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

10.c. Comments?

11.a. Complexity and formalism infrastructures: **(choose only one)**

_____ (1) The extent of valid application of common quantitative formalisms from physical sciences into socio-technical arenas is very large, and can be organized so that it is almost automatic.

_____ (2) Advocacy of unvalidated metaphors of formalisms from physical science must be tempered; justification and empirical evidence must be provided to support such advocacy.

11.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

11.c. Comments?

12.a. Complexity and spatial infrastructure: **(choose only one)**

_____ (1) There is no need to allocate space specifically for the purpose of portraying complexity.

_____ (2) Complexity demands that workspace allocation be designed especially to facilitate human learning.

12.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

12.c. Comments?

13.a. Complexity and linguistic infrastructure: **(choose only one)**

_____ (1) Natural language is adequate to represent complexity.

_____ (2) The inadequacy of natural languages (e.g., linearity) must be recognized; graphical nonlinear logic must be widely adopted in the domains of complexity to help overcome that inadequacy.

13.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

13.c. Comments?

14.a. Complexity and workplace infrastructure: **(choose only one)**

_____ (1) There is no reason to provide any special infrastructure at work to deal with complexity.

_____ (2) A workplace infrastructure dedicated to resolving complexity would satisfy a major demand of complexity.

14.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

14.c. Comments?

15.a. Complexity and scientific infrastructure: **(choose only one)**

_____ (1) It is appropriate to discuss science and technology as though there are no essential distinctions between them.

_____ (2) Complexity demands that technology used to help resolve problematic situations shall have been founded in science, and not just imposed by highly vocal advocates.

15.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

15. c. Comments?

16.a. Complexity and the quality of linguistic infrastructure: **(choose only one)**

_____ (1) Academics should be free to call any subject that they choose a "science" with no institutionally-established requirements and standards for linguistic quality control.

_____ (2) The word "science" must be restricted to those fields in which archival history, established laws, adequate empirical evidence, and adequate metrics have been established to form a science.

16.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

16. c. Comments?

17.a. Complexity and executive capacity: **(choose only one)**

_____ (1) The executive has the intellectual capacity to comprehend:

- All of the factors that are relevant to an executive decision.
- How the various factors are interrelated in a problematic situation.
- What alternatives are relevant when it is time to make a choice.
- How to prioritize the alternatives.
- At what time action should be initiated.

_____ (2) Complexity demands that organizations accept the inevitability of executive inadequacy to resolve complexity, as an inherent property of every human being.

17.b. How strongly do you feel about your choice? **(circle a number)**

4	3	2	1
Extremely strongly	Very strongly	Somewhat strongly	Not at all strongly

17. c. Comments?

Appendix B-3

Opinions about Choices

Respondents were asked to indicate how strongly they felt about their choices using the following Likert-type scale:

4 = Extremely strongly

3 = Somewhat strongly

2 = Very strongly

1 = Not at all strongly

We assigned negative values to support for killer assumptions and positive values to support for demands of complexity. Each display is preceded by the dichotomy presented to the participants. The number in brackets is the order in which the choice was presented in the first questionnaire. It is used throughout this paper for the sake of continuity.

<u>Complexity and Representational Infrastructure</u> [10]:

- Killer Assumption: Representation of complexity through metaphors related to common quantitative formalisms from physical sciences is strongly contributory to the resolution of complexity. (Chosen by 38 respondents.)
- Demands of Complexity: Complexity demands portrayal of the logic underlying the problematic situation. (Chosen by 67 respondents.)

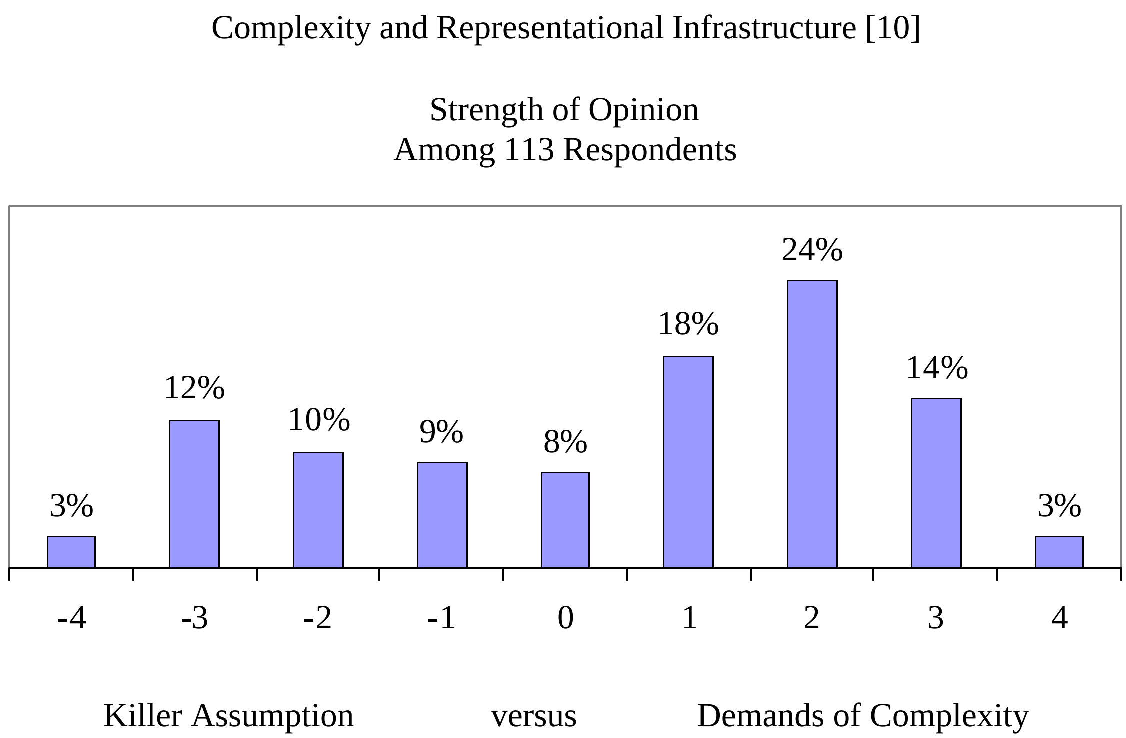


Figure B11. Strength of Opinion about Complexity and Representational Infrastructure

Complexity and Workplace Infrastructure [14]:

- Killer Assumption: There is no reason to provide any special infrastructure at work to deal with complexity. (Chosen by 31 respondents.)
- Demands of Complexity: A workplace infrastructure dedicated to resolving complexity would satisfy a major demand of complexity. (Chosen by 73 respondents.)

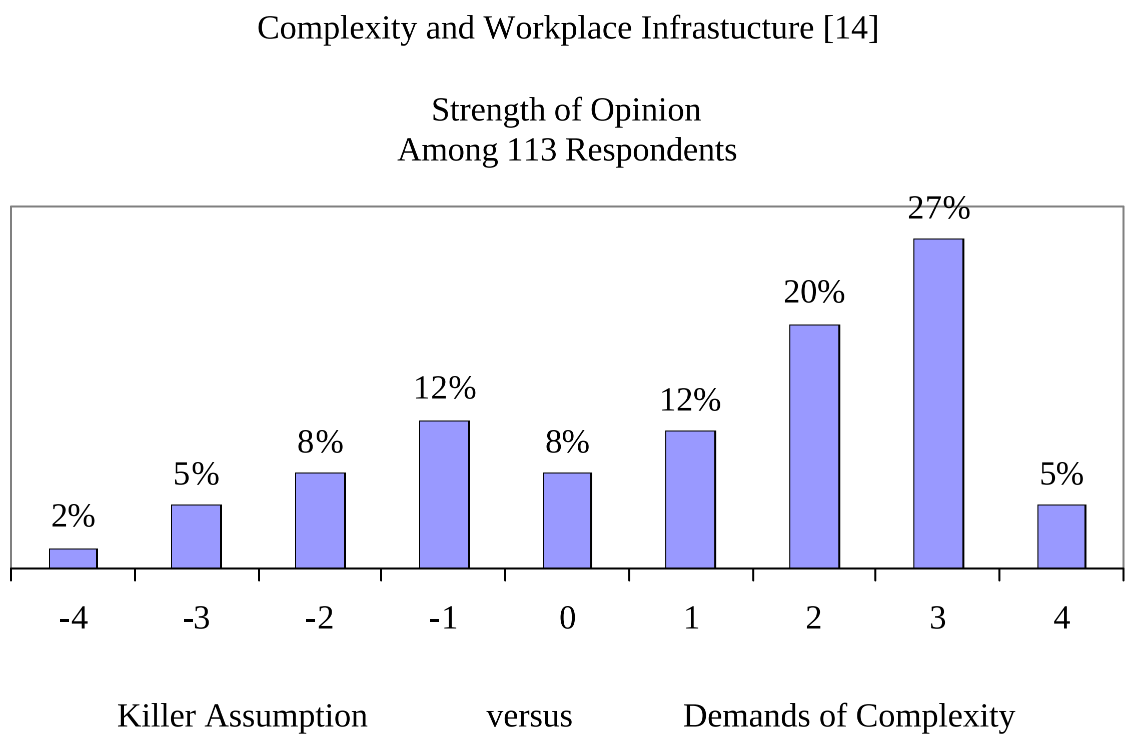


Figure B12. Strength of Opinion about Complexity and Workplace Infrastructure

Complexity and the Quality of Linguistic Infrastructure [16]:

- Killer Assumption: Academics should be free to call any subject that they choose a "science" with no institutionally-established requirements and standards for linguistic control. (Chosen by 24 respondents)
- Demands of Complexity: The word "science" must be restricted to those fields in which archival history, established laws, adequate empirical evidence, and adequate metrics have been established to form a science. (Chosen by 81 respondents.)

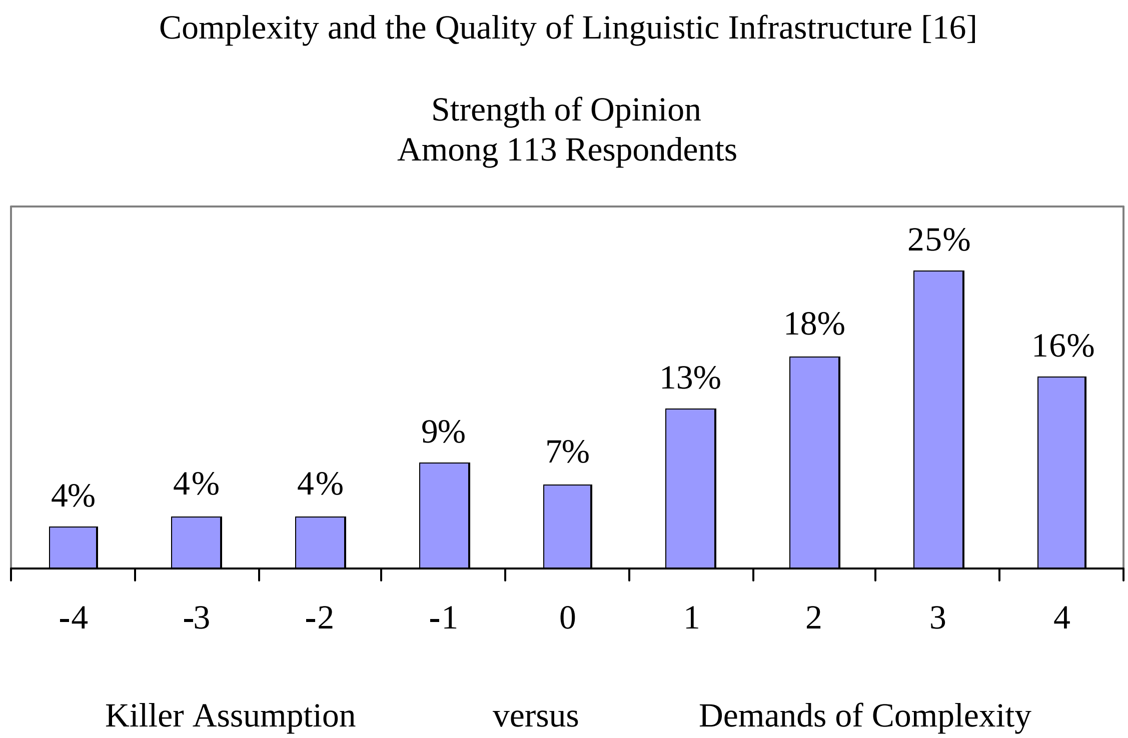


Figure B13. Strength of Opinion about Complexity and the Quality of Linguistic Infrastructure

<u>Complexity and Spatial Infrastructure</u> [12]:

- Killer Assumption: There is no need to allocate space specifically for the purpose of portraying complexity. (Chosen by 24 respondents.)
- Demands of Complexity: Complexity demands that workspace allocation be designed especially to facilitate human learning. (Chosen by 81 respondents.)

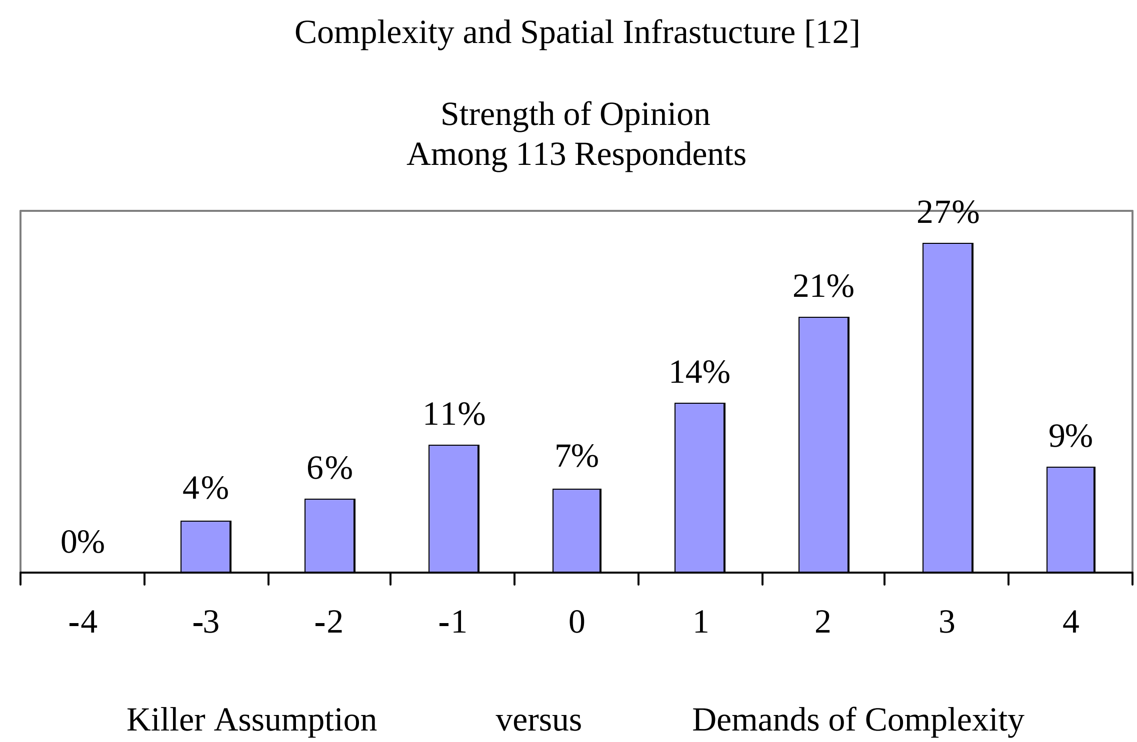


Figure B14. Strength of Opinion about Complexity and Spatial Infrastructure

<u>Complexity and Formalism Infrastructure</u> [11]:

- Killer Assumption: The extent of valid application of common quantitative formalisms from physical sciences into socio-technical arenas is very large, and can be organized so that it is almost automatic. (Chosen by 23 respondents.)
- Demands of Complexity: Advocacy of unvalidated metaphors of formalisms from physical science must be tempered; justification and empirical evidence must be provided to support such advocacy. (Chosen by 78 respondents.)

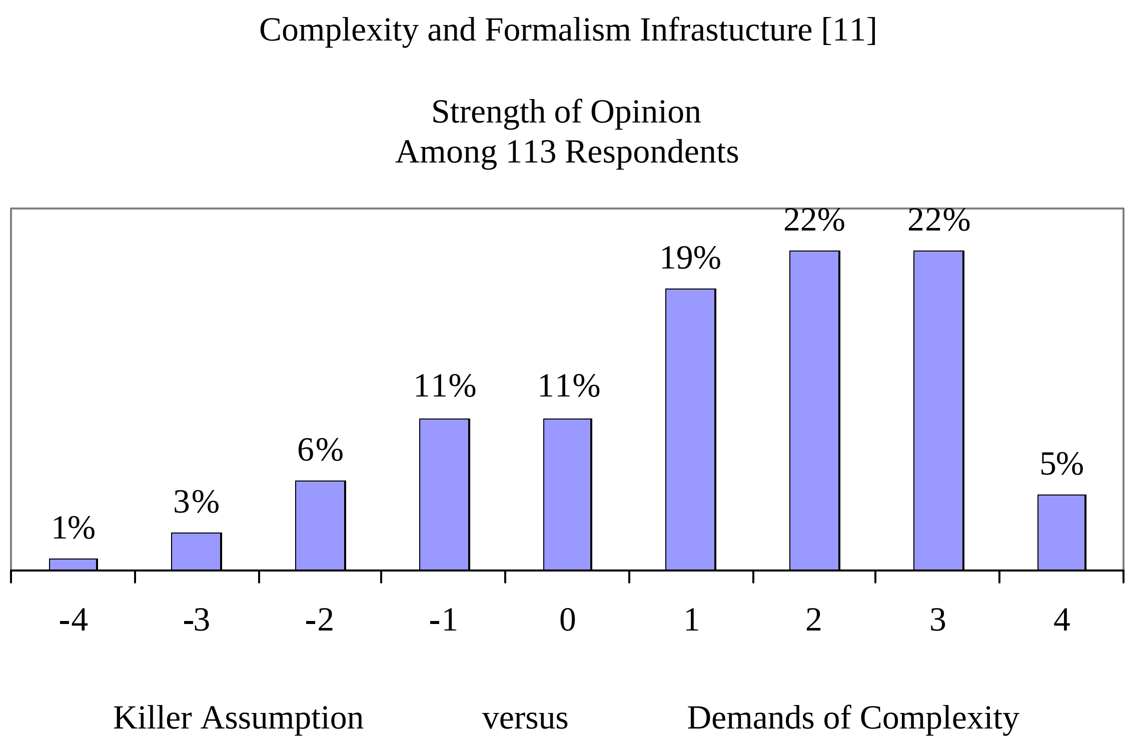


Figure B 15. Strength of Opinion about Complexity and Formalism Infrastructure

Complexity and Group Process Design [6]:

- Killer Assumption: Normal processes are sufficient to enable description and diagnosis of problematic situations involving high complexity. (Chosen by 23 respondents.)
- Demands of Complexity: The design of group processes must suit the character of complexity, rather than simply using conventional processes or allowing NO process design. (Chosen by 85 respondents.)

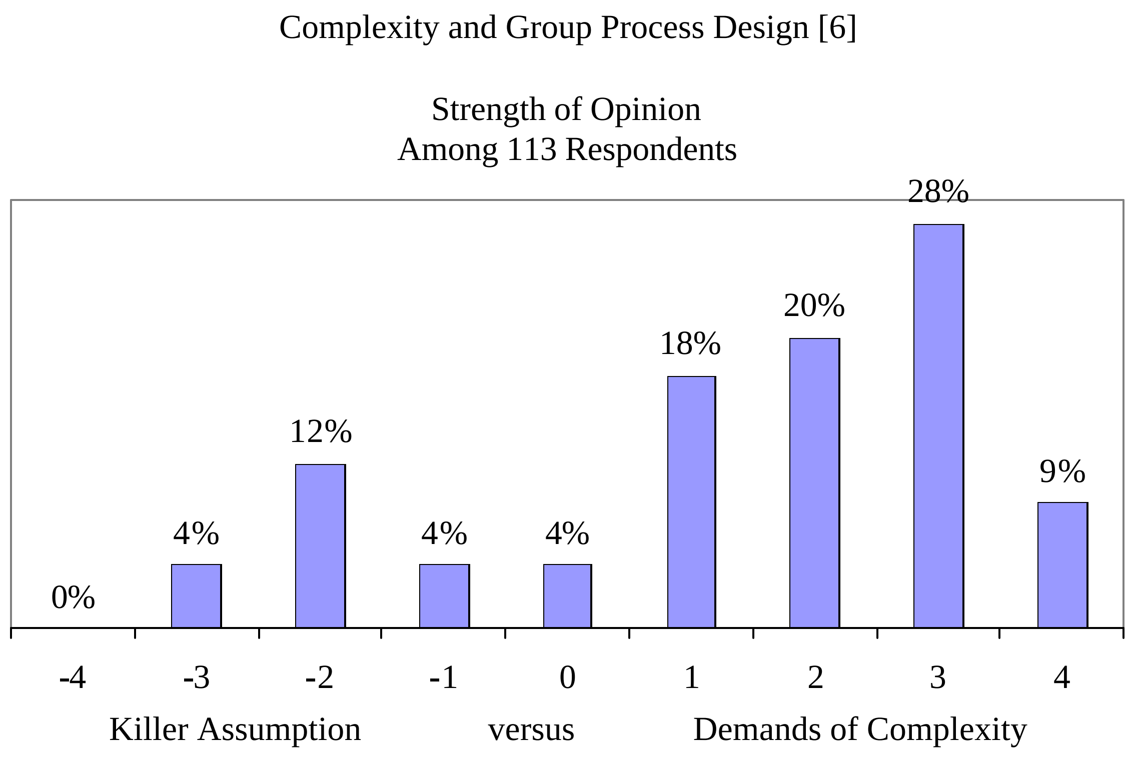


Figure B16. Strength of Opinion about Complexity and Group Process Design

<u>Complexity and Scientific Infrastructure</u> [15]:

- Killer Assumption: It is appropriate to discuss science and technology as though there are no essential distinctions between them. (Chosen by 22 respondents.)
- Demands of Complexity: Complexity demands that technology used to help resolve problematic situations shall have been founded in science, and not just imposed by highly vocal advocates. (Chosen by 82 respondents.)

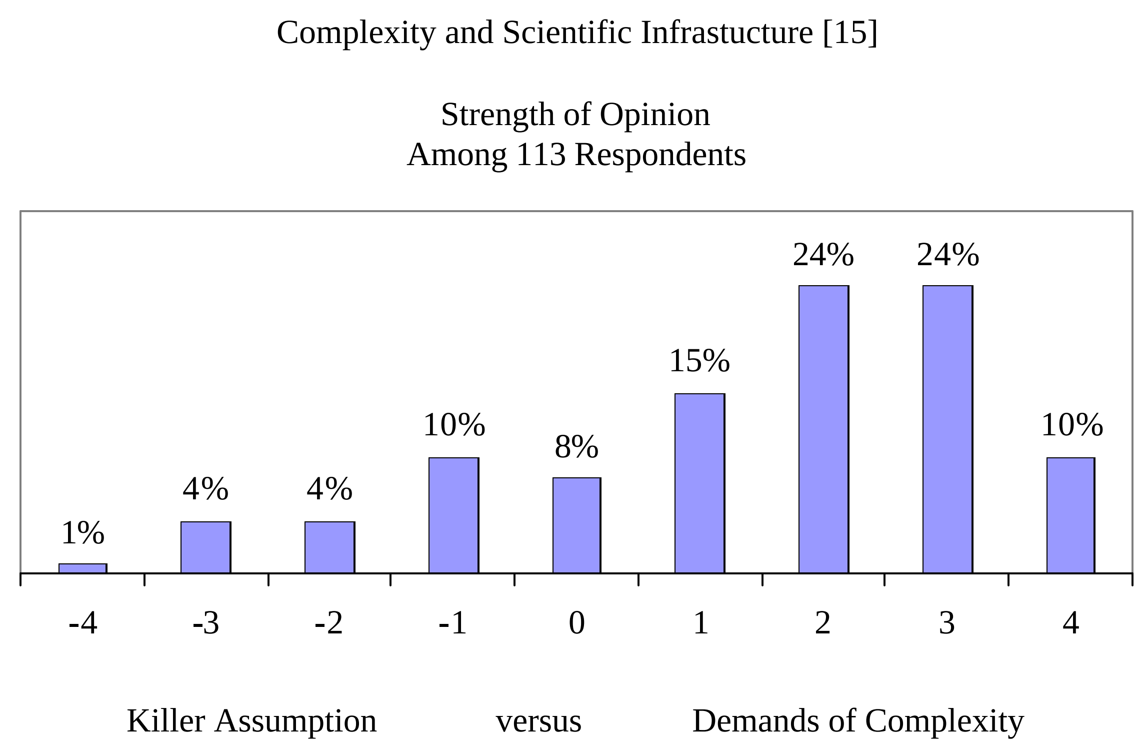


Figure B17. Strength of Opinion about Complexity and Scientific Infrastructure

<u>Complexity and Process Design</u> [4]:

- Killer Assumption: There is no need for empirical evidence to justify assumptions of relevance when designing processes to support resolution of complexity. (Chosen by 18 respondents.)
- Demands of Complexity: Scientifically respectable evidence must be applied in designing processes to support resolution of complexity. (Chosen by 89 respondents.)

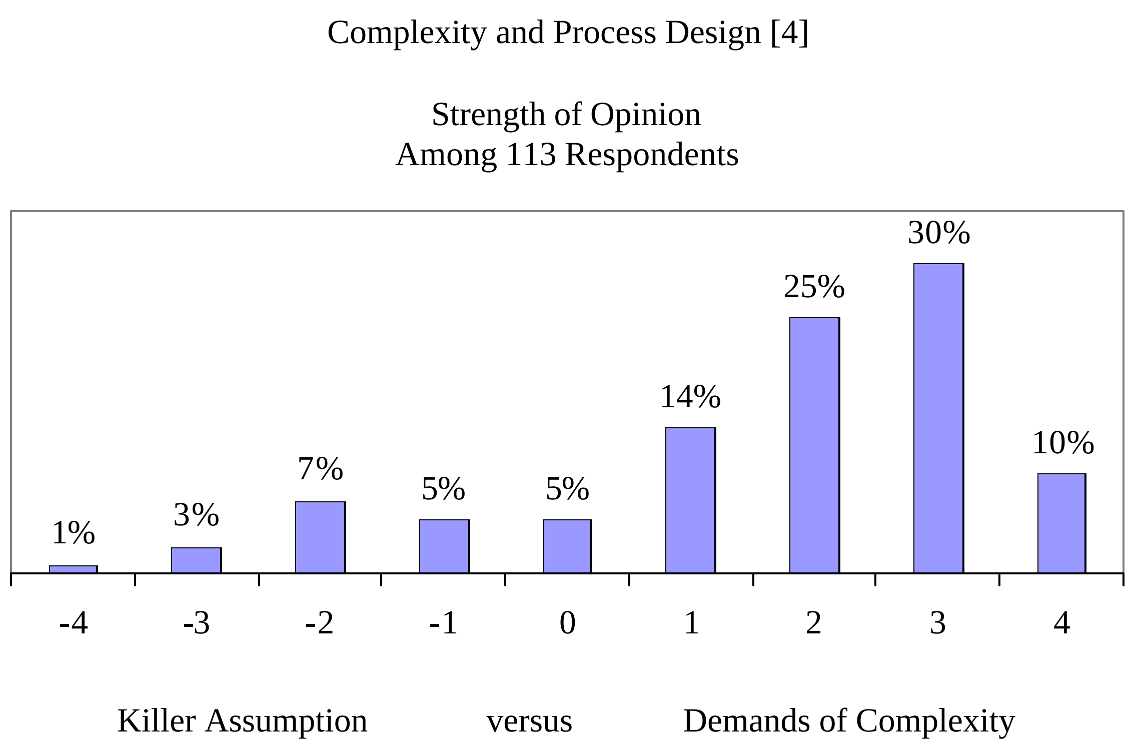


Figure B18. Strength of Opinion about Complexity and Process Design

Complexity and the Integration of Knowledge [8]:

- Killer Assumption: Simple amalgamation of disciplines will relieve disciplinary shortcomings in considering comprehensive domains. (Chosen by 16 respondents.)
- Demands of Complexity: Interdisciplinary programs must be designed to meet complexity's demands for learning efficacy. (Chosen by 88 respondents.)

Complexity and the Integration of Knowledge [8]

Strength of Opinion
Among 113 Respondents

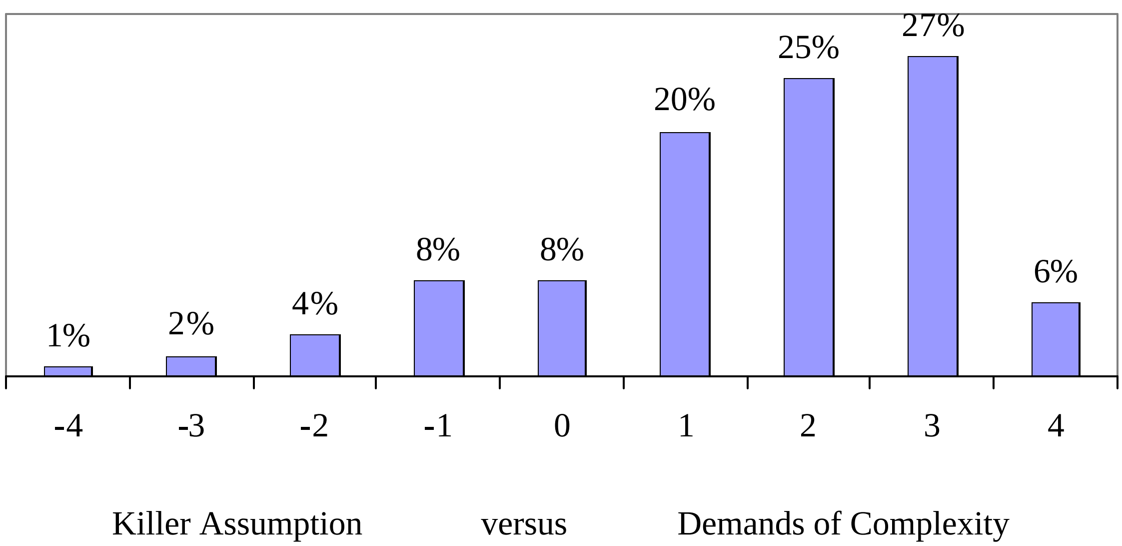


Figure B19. Strength of Opinion about Complexity and the Integration of Knowledge

Complexity and Types of Relationships [9]:

- Killer Assumption: There is seldom any reason to give the choice of types of relationships that are to be used in studies the same level of effort and depth of selectivity that are given to the elements that will be related (e.g. in model development.) (Chosen by 14 respondents.)
- Demands of Complexity: In problematic situations, the choice of relationships to be applied shall have as much prominence in the thinking of practitioners as does the choice of elements that are to be related. (Chosen by 89 respondents.)

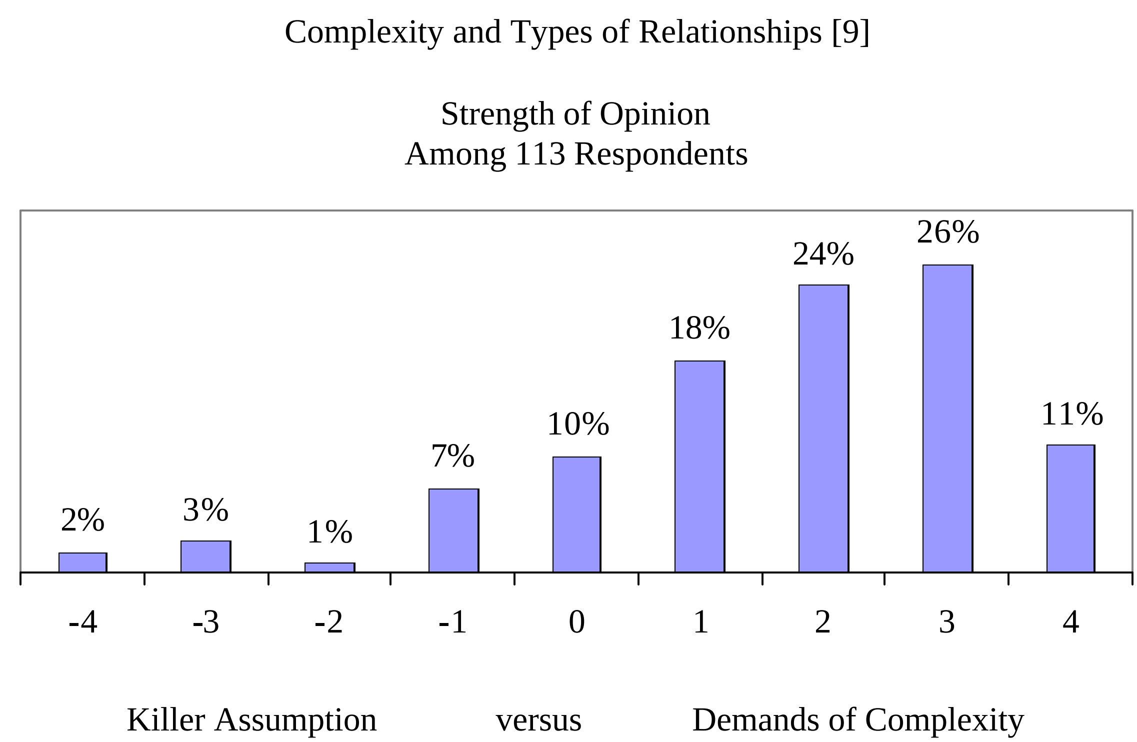


Figure B20. Strength of Opinion about Complexity and Types of Relationships

Complexity and Behavioral Research Findings [7]:

- Killer Assumption: The findings from behavioral science about individuals, groups, and organizations are too "soft" to have a major role in the management of organizations. (Chosen by 12 respondents.)
- Demands of Complexity: Linkages between thought leaders from the past and practices invoked in organizations must be widely understood, and taken into account in self-regulation of human behavior. (Chosen by 95 respondents.)

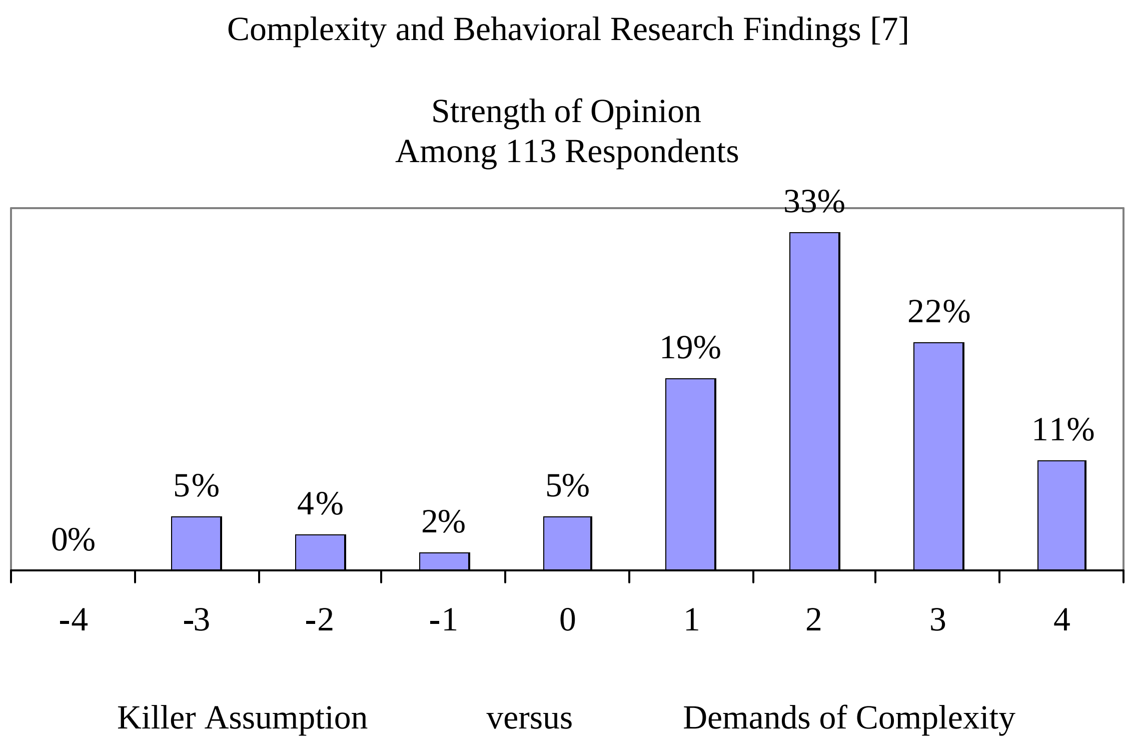


Figure B21. Strength of Opinion about Complexity and Behavioral Research Findings

<u>Complexity and Sources of Information</u> [5]:

- Killer Assumption: If information comes from a "prestigious" source, it need not be questioned. (Chosen by 6 respondents.)
- Demands of Complexity: The authority of "prestigious institutions" must be tested against the scientific base that ought to be provided to support that authority. (Chosen by 106 respondents.)

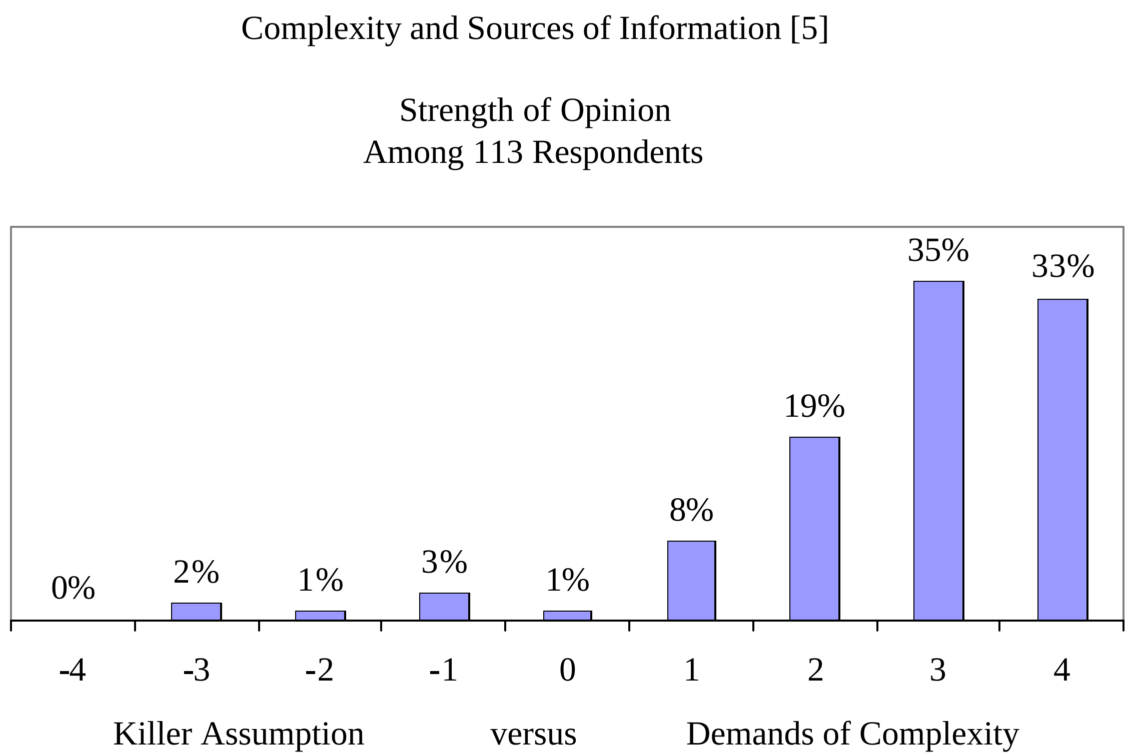


Figure B22. Strength of Opinion about Complexity and Sources of Information

<u>Complexity and History</u> [3]:

- Killer Assumption: In high-technology environments of today, learning from history is largely irrelevant to organizational decision making. (Chosen by 3 respondents.)
- Demands of Complexity: The lessons of history must be recognized and incorporated in learning situations. (Chosen by 109 respondents.)

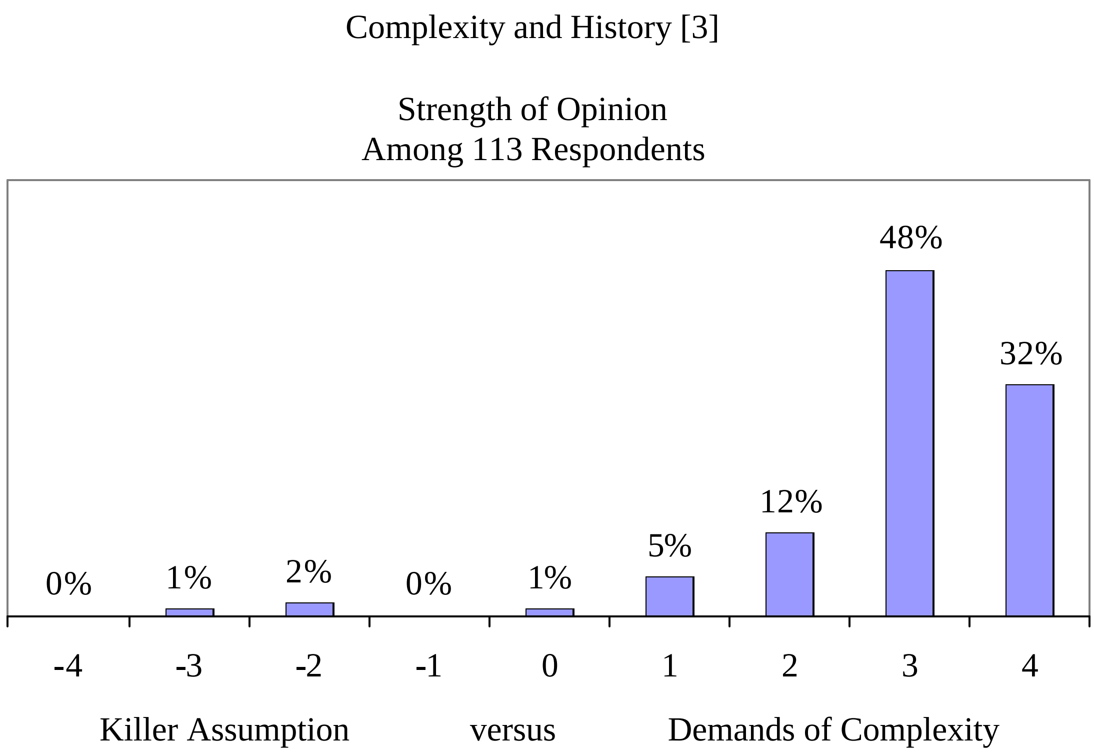
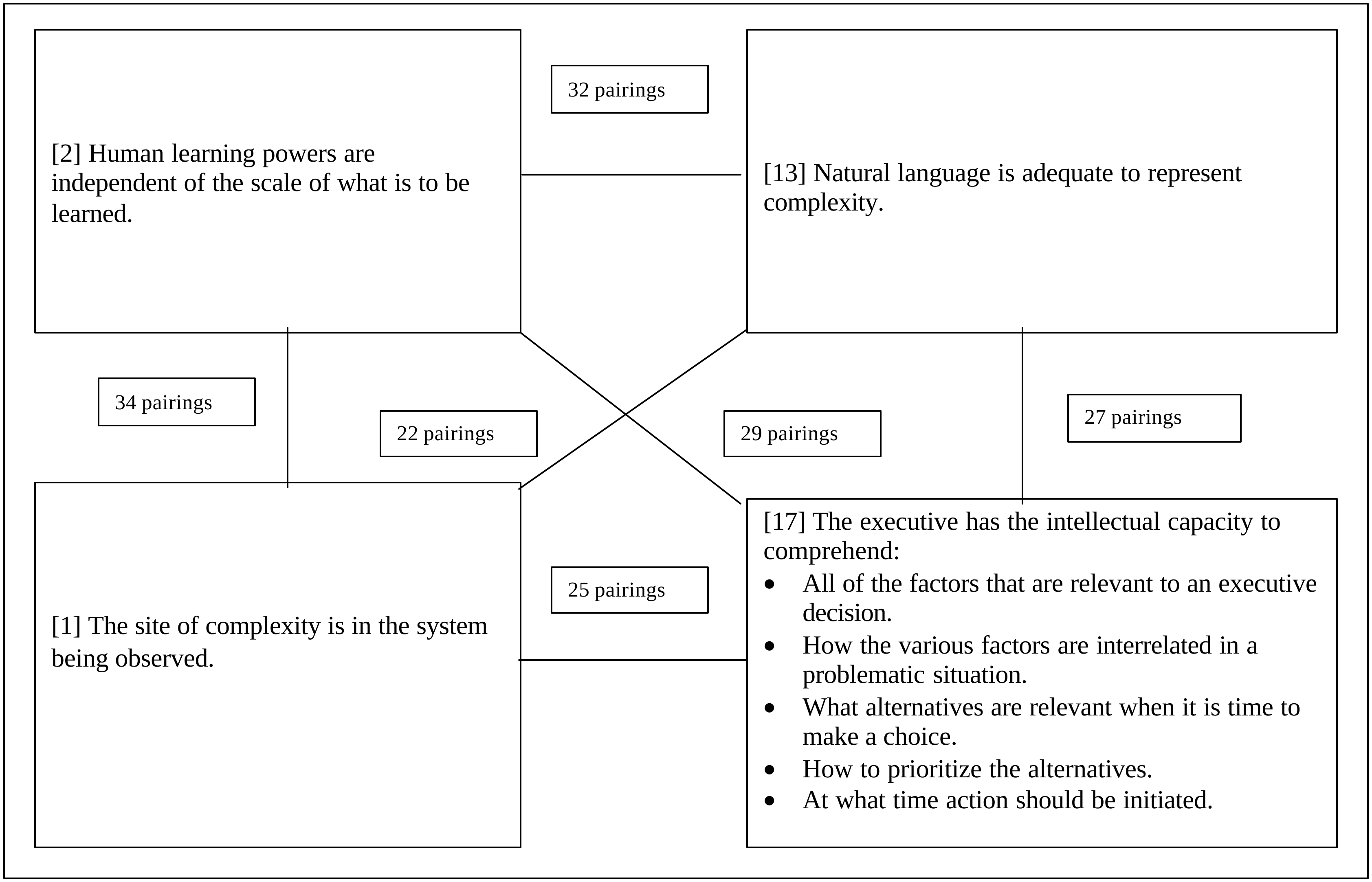


Figure B23. Strength of Opinion about Complexity and History

Figure B8. Most Frequent Pairings



Appendix C

The Nature of Systems and Problem Solving

Overview

This study focused on obtaining participant opinions regarding the nature of systems and problem solving. Results of two prior studies concerning complexity had led us to wonder about participants' perspective regarding systems theory. Those studies involved over 700 highly schooled engineering- and management-oriented acquisition professionals attending courses in systems acquisition management at the Defense Systems Management College (DSMC) during the period January 1996 to December 1998. The curriculum of the systems acquisition management course they were attending addressed both theory and practice in systems management tools and techniques, yet their survey responses had often reflected a simplistic approach to problem solving. We therefore determined that important insights about this phenomenon might be gained by obtaining attendee responses to the following three open-ended questions:

- What definition of "system" do you think is most useful?
- How might "system behavior" be best understood?
- What does "problem solving" involve?

Analysis of the responses to questionnaires administered during January 1999 disclosed a predominantly Newtonian perspective among the participants. Two thirds of the respondents felt that system behavior could be best understood through observation and analysis. Almost the same proportion described a problem solving process that did not include getting feedback to determine if the chosen solution was working. Such an approach may be appropriate for well-defined mechanistic systems, but is inappropriate when attempting to manage acquisition programs characterized by non-deterministic behavior.

Statement of the Problem

Results of the first two studies had led us to wonder about participants' perspective regarding systems theory. There is a growing body of literature in the field of systems theory concerning the non-linear and emergent characteristics of contemporary socio-technical systems (Cambel 1993, De Greene 1993, Kiel 1994, and Waldrop 1992.) The fact that these characteristics apply to defense systems has been recognized in such acquisition approaches as pre-planned product improvement (P^3I), evolutionary acquisition, and spiral development. As previously stated, most survey participants held undergraduate and graduate degrees in engineering or business management subjects. The curriculum of the systems acquisition management course they were attending addressed both theory and practice in systems management tools and techniques, yet survey responses had often reflected a fairly simplistic approach to problem solving.

Research Question

This study focused on obtaining opinions regarding the nature of systems and problem solving. We determined that important insights about this phenomenon might be gained by obtaining attendee responses to the following three open-ended questions:

- What definition of "system" do you think is most useful?
- How might "system behavior" be best understood?

- What does “problem solving” involve?

Research Design

A research design based on non-random purposive sampling techniques was adopted in an effort to obtain a sufficient number of survey responses from which to draw useful information. Self-administered questionnaires were used to gather subjective responses to questions concerning the nature of systems and problem solving[1]. A combination of non-parametric statistical analysis as suggested by Siegel & Castellan (1988) and content analysis as described by Weber (1990) was selected as the most appropriate set of procedures for analyzing this data. Content analysis procedures described by Weber (1990) were used to analyze responses to the three questions. The purpose of this analysis was to identify commonality among respondent’s opinions concerning the nature of systems and problem solving. Content analysis is an inductive process. It is highly subjective, time consuming, and laborious. Content analysis procedures require the investigator to develop an intimate relationship with the narratives being analyzed in order to gain a sense of intended meaning from what is stated and the context in which it is stated. The process requires the investigator to select a word or phrase to accurately capture the central thought in each response. A count of these words and phrases then provides input for a quantitative assessment of common ideas among all respondents[2]. Use of non-random purposive sampling techniques permit us to describe what was discovered, but not to state generalizable conclusions concerning the

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[1] A copy of the questionnaire is located at appendix C-1.
[2] Copies of responses to survey questions, annotated with assigned tag words, are available from the author.

associations or patterns uncovered. This restriction was deemed acceptable since participant demographics generally reflect the composition of the Department of Defense acquisition workforce.

Research Participants

Participants included highly schooled engineering- and management-oriented acquisition professionals attending an Advanced Program Management Course (APMC), an intensive 14 week course in systems acquisition management presented by the Defense Systems Management College (DSMC) located at Fort Belvoir, VA. The college is considered to be the premier center for learning about the U. S. Department of Defense (DOD) systems acquisition process. Successful completion of the course is considered essential for selection as a program manager of a major defense system acquisition program. Attendees represent a group of public and private sector decision-makers faced with managing the acquisition and life cycle support of DoD systems costing American taxpayers billions of dollars. Virtually all survey respondents had four or more years of college education. Most held undergraduate and higher degrees in an engineering or business discipline. Many had several years of experience in the field of systems acquisition management before coming to DSMC.

Research Method

A one-page questionnaire asked participants to answer three questions concerning the nature of systems and problem solving. The three questions were:

- What definition of “system” do you think is most useful?
- How might “system behavior” be best understood?

- What does “problem solving” involve?

A total of 360 questionnaires were distributed to acquisition professionals during regularly scheduled class periods. A total of 305 completed surveys were returned for a response rate of 85%.

Results

System Definitions

The first question on the survey asked respondents what definition of “system” they thought was most useful. One hundred sixty three of the 305 respondents (53%) described a system as being comprised of elements working together to perform a function. Forty-two respondents (14%) described a system as a fully functional end item. This second description fits what the acquisition manager is responsible for obtaining and delivering to the war fighter. It connotes a combination of hardware and software configured to perform a specified function. Both responses are in consonance with the official definition of a major system contained in DOD 5000.2-R (23 March 1998). That document details the mandatory procedures for major systems acquisition programs. The definition reads, “A combination of elements that shall function together to produce the capabilities required to fulfill a mission need, including hardware, equipment, software, or any combination thereof….” (Section C. Definitions).

Sixteen respondents (5%) described a system as a transformational process rather than a product of the acquisition program. The remaining responses (28%) did not readily fit into convenient categories.

Viewed from a different perspective, we found that only eighteen respondents (6%) defined a system in terms of its environmental context. Conversely, 94% of the respondents seemed to think of a system as a self-contained entity disassociated from its surroundings. This was surprising since DoDD 5000.1 (15 March 1996) says the following about defense systems acquisition programs:

> Acquisition programs shall be managed to optimize total system performance and minimize the cost of ownership. The total system includes not just the prime mission equipment, but the people who operate and maintain the system; how systems security procedures and practices are implemented; how the system operates in its intended operational environment and how the system will be able to respond to any effects unique to that environment (such as Nuclear, Biological and Chemical (NBC) or information warfare); how the system will be deployed to this environment; the system's compatibility, interoperability, and integration with other systems; the operational and support infrastructure (including Command, Control, Communications, Computers, and Intelligence (C^4I)); training and training devices; any data required by the system in order for it to operate; and the system's potential impact on the environment and environmental compliance. (Section D. Policy)

Understanding System Behavior

A second question also addressed the nature of systems. It asked how "system behavior" might be best understood. The intent of the question was to determine the extent to which respondents believed overall system performance could be measured. A total of 206 out of 305 respondents (68%) indicated that system behavior could be best understood through observation or analysis of performance. We interpreted these responses as indicative of reductive reasoning typical of a mechanistic systems perspective.

Twenty-five respondents (8%) defined what system behavior was rather than how it should be measured. Another 25 indicated that they didn't have an answer or didn't believe systems had behavior. The remaining responses (16%) did not readily fit into convenient categories.

The Nature of Problem Solving

A final question asked, what does "problem solving" involve. Virtually all responses indicated that problem solving was a process. However, the description of the process was very informative. Only 110 respondents (36%) described a process that included obtaining feedback on the outcome of decisions. The other 64% described a process that ended upon reaching the decision on actions to be taken to solve the problem at hand.

Discussion

Taking the answers to all three survey questions into account left us with the impression that respondents tended to view systems as discrete entities that could be understood in toto through analysis and that the problem solving process focused more on reaching a decision than insuring it was effective. There was no indication that systems were viewed as evolutionary or emergent in nature or that the results of decisions might not be readily observable.

Conclusions

These findings confirmed our suspicions that a large group of defense acquisition management personnel view systems from a Newtonian paradigm. This is an approach that calls for analysis and control of observable outcomes and drives managerial attention toward near-term time horizons. Such an approach may be appropriate for well-defined mechanistic systems, but is inappropriate when attempting to manage acquisition programs characterized by non-linear and non-reversible behavior.

Appendix C-1

A QUESTIONNAIRE ABOUT SYSTEMS MANAGEMENT

Please take a few minutes to answer the following questions. If you can recall an "authority" for any of your answers, please note it (them).

1. What definition of "system" do you think is most useful?

2. What does "problem solving" involve?

3. How might "system behavior" be best understood?

Appendix D

Correspondence from Dr. George Friedman to Dr. John Warfield

John Warfield, July 27, 1999
FAX: (703) 993-2996

Here is the material I promised you in this morning's telecon:

a) The vu-graph that I plan to use in the USC seminar next month,

b) The ideas behind the vu-graph:

One of the most demanding tasks I had as Northrop's chief technical officer was to review the failures of new systems and technologies as they were going through their final test phases. These failures were especially distressing since we felt we had applied the best engineers and systems processes on these new programs.

The vast majority of the failures were due to two fundamental causes:
1) The construction and assembly of the components did not follow the engineers' specifications,
2) The models the engineers used to predict performance were incomplete; many of the interactions were omitted, despite the presence of massive computer resources.

The second cause was more prevalent than the first.

This, in my mind, is yet another example of the dimensional limitations of our cognitive equipment. We have the illusion that we can comprehend a complex problem in all the necessary dimensions, but we are really limited to but a half dozen or so dimensions that can be perceived simultaneously.

Based on the book, Richard Moore, *Over 1000 Physics Formulae*, College Lane Publishers, 1984, I performed a simple study of the dimensionality of what is representative of the first 3000 years of mankind's quantitative modeling of the scientific and engineering worlds. The result: Over 75% of these equations had a dimensionality between 2 and 6. To inject a little humor for my grad students, I unhumbly modified it to:

The Friedman rule of σ, π and e:
Over plus or minus one σ of all relations have a dimensionality within π plus or minus e.

Philosophical question: Is the universe really so loosely coupled? Or, is this small dimensionality due to the fact that the humans who developed the equations controlled their experiments in accordance with their cognitive limitations? I think the latter.

Warmest regards,
George Friedman
Encino, CA

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Curriculum Vitae

George H. Perino, Jr. was born in Nyack, NY on April 1, 1939. He holds the following degrees: Bachelor of Science in Accounting, Stetson University, 1961; Master of Arts in History, Stetson University, 1970; Master of Business Administration in Finance and International Business Management, Loyola University of Chicago, 1972; Doctor of Philosophy in Public Policy, George Mason University, 1999.

Dr. Perino has over 25 years of experience in Department of Defense systems acquisition, both within government and industry. He is a 1976 graduate of the 20-week Program Management Course taught at the Defense Systems Management College located at Fort Belvoir, VA.

Dr. Perino's research interests span several related areas with emphasis in corporate financial management, science and technology, entrepreneurship, and psychology. He has had articles published in professional journals to include the Program Manager, Systems Research and Behavioral Science and the Journal of Psychological Type.